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Influence of Density of Sand on the Axial Force, Shear Force and Bending Moment in Driven Nailed Soil Wall

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***Abstract*—Soil nailing is an in situ earth reinforcement technique in which technique in which steel bars are usually used as passive inclusions primarily used to retain excavations or vertical cuts and to stabilize slopes. It is an easy flexible and economical method of soil reinforcement comprising of placing closely spaced steel rods for restrict the displacement and arrest the decompression during and after excavation. In this study a parametric study was carried out on the driven soil nail walls using PLAXIS 2D software. A soil system stabilized using soil nails was numerically simulated and analyzed for its behavior under varying the type of soil, Nail inclination and batter angle and under varying nail length. The results are compared based on the maximum horizontal displacement, axial tension forces in the soil nail, shear force and bending moment at the interface of the critical failure surface and Global Factor of safety.**

Keywords—Soil nailing, slope stability, global factor of safety, Finite Element Method

I. INTRODUCTION

Soil Nailing is an in-situ earth reinforcement technique in which steel bars are usually used as passive inclusions primarily used to retain excavations or vertical cuts and to stabilize slopes. It is an easy flexible and economical method of soil reinforcement. It is a top down construction technique used extensively in India and abroad. Steel bars are used as reinforcement essentially work in tension and partially in bending and shear. They are placed parallel to each other and slightly inclined downwards. The effectiveness of the soil nailing structures is a resultant of the complex soil structure interaction among, in-situ soil, stiffness of reinforcement and spacing. In order to evaluate the performance of the soil nailing system, in terms of pull out resistance, various modelling techniques such as FEM and FDM are used to simulate the soil nail system and to analyse the stress condition therein. The results are compared with the field observation and the conventional design based on FHWA manual (2012). The objective of this study is to find the effect of the different densities of sand, the changes in the geometry of the soil nail wall and nail length on the axial force, shear force and bending moment in addition to global factor of safety and horizontal displacement using numerical simulation with the help of finite element software PLAXIS 2D.

The stability of the soil nailing system depends not only on the dimensions of the excavation of the soil and nails but also depends on the density of soil to be stabilized.

II. LITERATURE REVIEW

Babu and singh [6] appraised the soil nailing design by designing three soil nailed wall to support vertical cuts of heights 6m, 12m and 18m based on conventional design procedure. The walls were numerically simulated using PLAXIS 2D. The design parameters such as lateral displacement and factor of safety obtained using conventional design procedure were evaluated and compared. The conventional design procedure was found to be conservative and provided a safe design. The contribution of shear and bending stiffness were found to be less significant, as they were observed to be mobilized only after relatively large displacements taking place along the slip surface. The numerical simulations were in good agreement with previous research findings.

Ghareh [3] studied parametric assessment of soil-nailing retaining structures in cohesive and cohesion less soil sand the effect of shear strength parameters such as C and Ø and surcharge on the axial force, shear force and bending moment on shotcreted increases the wall displacements. On the other hand, increase in shear strength parameters also increase the axial load, shear force and bending moment, but reduce the horizontal movement to a great extent. It was found that the highest wall movement in cohesion less soil occurred in the base of the wall. In cohesive soils the highest wall movement occurred near the base. Even a small increase in the cohesion reduced the wall movement considerably.

Midhula and chandrakaran [4] employed PLAXIS 2D in this study and generated a model for a 10m vertical cut in lateritic soil with horizontal nails. It was observed that lateral deformation was reduced by about 10% and FOS increased by almost 1.2times when compared to that of slope without nail. A detailed parametric study was conducted by varying the properties of in-situ soil nail and facing. It was observed that the FOS is dependent on the nail orientation and hence optimum nail orientation for various slopes was obtained. This study affirmed that Plaxis 2D can be used for predicting general behaviour of soil nailed structures.

Babu [5] conducted a study on stability analysis and performance of driven nailed soil walls. Three soil nail walls in Chennai and analysed based on the simplified trial wedge method, Snailz program, PLAXIS 2D and PLAXIS 3D. The observations on the Global Factor of Safety, Maximum Lateral Displacement, Axial Force, Shear Force and Bending Moment acting on the nails were compared and documented.

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III. NEED FOR THE STUDY

The literature available in soil nailing is mostly based on the drilled nails or grouted nails. Nowadays, driven nails are extensively used in the field for temporary retention of excavations and slope stabilization in India and abroad. In the design of soil nails, the shear force and bending moment are not taken into account hence the design becomes conservative. Hence, it was proposed to study the effect of different soil densities on the forces acting on the soil nails especially the reduction in global sector of safety for an economic design.

IV. ANALYSIS USING PLAXIS 2D

The consideration of many parameters in the analysis of the soil nailed walls makes the theoretical calculations more complex. Therefore in this study detailed numerical investigations were carried out using the finite element software PLAXIS 2D software. The soil nail walls of different geometry considered for the present analysis to understand the influence of various parameters are listed below.

1. Three different densities of sand (loose , medium dense and dense)
2. Two different in batter angle, β and nail inclination, i (always β=i)(10º,30º)
3. Three different nail lengths (4m, 4.5m & 5m)

The results that are discussed are Influence of soil density and, nail inclination and nail length, Maximum horizontal displacement, Maximum axial tensile force in the soil, Maximum Shear force and bending moment and Global factor of safety.

A. About PLAXIS 2D

PLAXIS 2D is a finite element package created for the two dimensional analysis of deformation, stability and ground water flow in the geotechnical engineering. Geotechnical applications involve advanced constitutive models for the simulation of the non-linear, time dependent and anisotropic behaviour of soils and rock. In addition to the modelling of the soil, many geotechnical projects involve the modelling of structures and the interaction between the soil structures. PLAXIS 2D is equipped with the features for accommodating various aspects of complex geotechnical structures.

In this study, the simulation in PLAXIS 2D is done as per PLAXIS bulletin spring issue 2009. The important aspect considered in the simulation are connections of soil nails to the wall facing, depth and width of soil layer below the excavation, material model, interface elements and equivalent nail parameters. The material models used to simulate the in-situ soil for the excavations are Hardening soil (HS) model. The soil nails are simulated as plate element. Generally for loading problem in soils, Mohr coulomb model are used but based on detailed study, Babu and Singh (2009) recommended using advance models such as HS model or HS small strain model in -lieu especially for soil nailing. The nails are modelled as plate structural elements and the material behaviour is considered as elastic.

B. Validation of Software and Modeling

To validate the software and meshing the data reported by Babu and Singh (2009) is considered and the input values are listed in Table I and Table II.

TABLE I. SOIL NAIL WALL GEOMETRY AND OTHER PARAMETER (BABU AND SINGH 2009)

Parameter	Value
Vertical height of the wall H (m)	10.0
Face batter β (degree)	0.0
Back slope angle a (degree)	0.0
Nailing type	Grouted
Grouted nails and facing Material model	Elastic
Yield strength of reinforcement fy (MPa)	415.0
Elasticity modulus of reinforcement E (GPa)	200.0
Elasticity modulus of grout (concrete) Eg (GPa)	22.0
Diameter of reinforcement d (mm)	20.0
Drill hole diameter DDH (mm)	100.0
Length of nail L (m)	7.0
Inclination w.r.t horizontal i (degree)	15.0
Spacing Sh x Sv (m x m)	1.0 x 1 .0
Facing thickness t (mm)	200.0
Mesh Element	15 Nodded triangular element
Mesh type	Very Coarse

Analyses were carried out for the input parameters listed in table II and table III and one output is shown in Fig. 1 and the partial results are compared in table IV.

TABLE II. SOIL MODEL PARAMETERS (BRINGREVE AT. 2006)

Parameter	Mohr Coulomb Model
Cohesion, c (kN/m2)	10.0
Friction Angle, Ø (degree)	27.5
Dilatancy Angle Ψ (degree)	0.0
Unit weight γ (kN/m3)	19.0
Modulus of elasticity of soil, E (kN/m2)	30,000
Poisson's Ratio, μ	0.3

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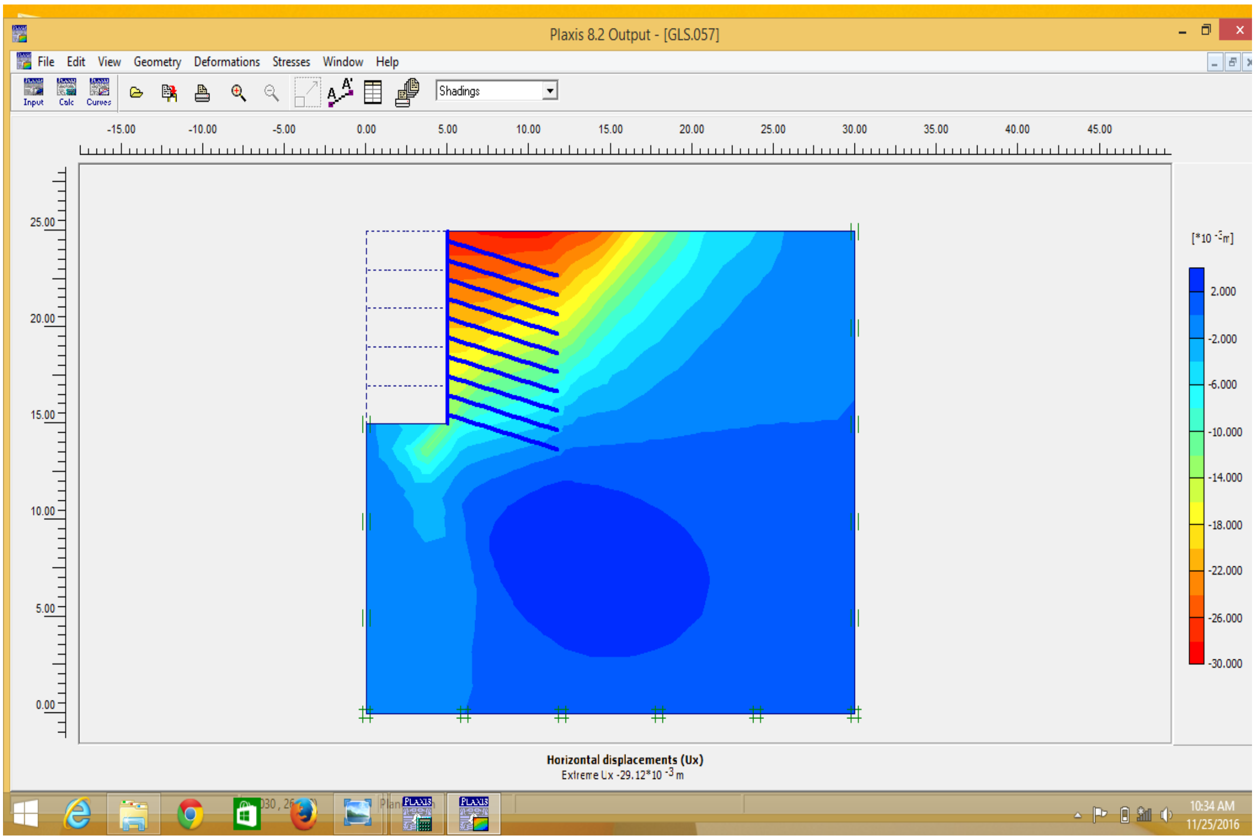

Fig 1. Horizontal Displacements in Soil Nails after Excavation

From Table III, we observed that Global Factor of Safety and Maximum Horizontal Displacement (mm) obtained from present analysis are comparable. Hence further analyses are preceded.

TABLE III. COMPARISON OF GLOBAL FACTOR OF SAFETY & MAXIMUM HORIZONTAL DISPLACEMENT (MM) AT THE END OF EXCAVATION.

Mesh Density	Global Factor of Safety		Maximum Horizontal Displacement (mm)	
	Babu and Singh 2009	Present study	Babu and Singh 2009	Present study
Very Coarse	1.61	1.59	20.93	29.12

TABLE IV. INPUT PARAMETERS FOR DEFINING THE GEOMETRY OF 5M SOIL NAIL WALL

Ht of wall, H	5 m
Wall Batter angle and nail inclination to Horizontal, β& i*	10° and 30°
Length of nail, L	4m,4.5m &5 m
Number of Nails, n ,Size of Nail	5, 20mm steel rod
Type of Facing	M 20 shotcrete
Thickness of facing, t	50mm
Depth of each cut of excavation	1 m
Type of Sand	Loose, Med-dense and Dense sand
Spacing of nails Sh x Sv	1m x 1m

C. Analysis through PLAXIS 2D

Analyses were conducted using 5 m height of wall by changing the length of the nails, wall batter and inclination of nail to the horizontal and densities of sand. The different input parameters for defining the geometry of 5 m soil nail wall are presented in table IV. Analysis was done for each combination of the above variations and the results were compared.

The nail facing input parameters are presented in table V.

TABLE V. INPUT PARAMETER FOR DEFINING THE DRIVEN NAILS AND FACING

Identification	Nails (Driven)	Facing
Material Type	Elastic	Elastic
Material Description	20mm dia MS rod	M20 Shotcrete
Modulus of elasticity, E, GPa	200	22.36
EA, kN/m	6.283 x 10^4 kN/m	1.118 x 10^4 kN/m
EI, kNm²/m	1.57 kNm²/m	232.924 kNm²/m
Diameter / Thickness	20mm, steel rod	50mm
Weight, w kN/m³	78.50	25
Poisson's Ratio	0.27	0.20
Element used	Plate Element	Plate Element

In this study the type of soil stabilized is taken as sand of different densities. Accordingly the various input parameters of define the soil condition are printed in Table VI.

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TABLE VI. INPUT PARAMETERS FOR DEFINING THE SAND

Description	Loose Sand	Medium Dense Sand	Dense Sand
Material Model	Hardening Soil	Hardening Soil	Hardening Soil
Material Type	Drained	Drained	Drained
Dry unit weight, γ_d kN/m^3	16	19	21
Saturated unit weight, γ_{sat} kN/m^3	18	21	22
Permeability in m/day, k_x & k_y	86.4	8.64	0.86
E^{ref}_{50}, kN/m^2	2.0 x 10^4	3.0 x 10^4	4.0 x 10^4
E^{ref}_{oed}, kN/m^2	2.0 x 10^4	3.0 x 10^4	4.0 x 10^4
E^{ref}_{ur}, kN/m^2	6.0 x 10^4	9.0 x 10^4	1.20 x 10^5
Cohesion, C_{ref}	1.00	1.00	1.00
Angel of Internal Friction. Ø	30 °	35 °	40 °
Distance angle, Ψ	0 °	5 °	10 °
Interface	Rigid	Rigid	Rigid
R_{inter}	1.00	1.00	1.00
Power, m	0.5	0.5	0.5

Numerical modelling and analyses are carried out for all combination of soil condition, nail length, nail inclination and batter angle. Some of them are shown in Fig 2 to Fig 4.

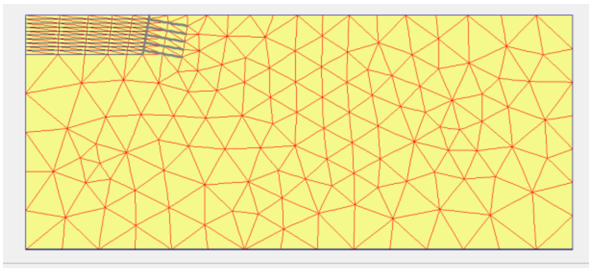

Fig 2. Mesh before excavation of soil nail wall with with β=i= 10 degree in loose sand.

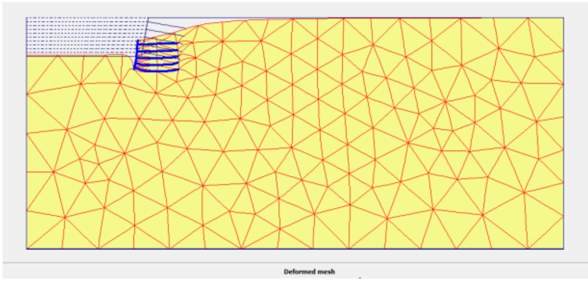

Fig 3. Deformed mesh after excavation of soil nail wall with with β=i= 10 degree in loose sand

The results are obtained from different analyses are presented and discussed in the proceeding section.

V. RESULT AND DISCUSSION

D. Loose Sand

The results obtained from different analysis by varying the different wall batter and nail inclination to horizontal (both being the same) and nail lengths for loose sand are presented in the table VII.

Influence of wall batter angle β, and nail inclination to horizontal

For all nail length, the values of maximum horizontal displacement and maximum axial force are higher at β=i=10º whereas the maximum shear force and maximum bending moment values varies based on the nail number from top.

For 5 m nail length the maximum shear force and maximum bending moment values are higher at β=i=30º. For 4.5 m and 4 m nail length the maximum shear force and maximum bending moment values at first and third nail are higher at β=i=30º and it is observed to be higher at β=i=10º in case of second, fourth and fifth nail number from top.

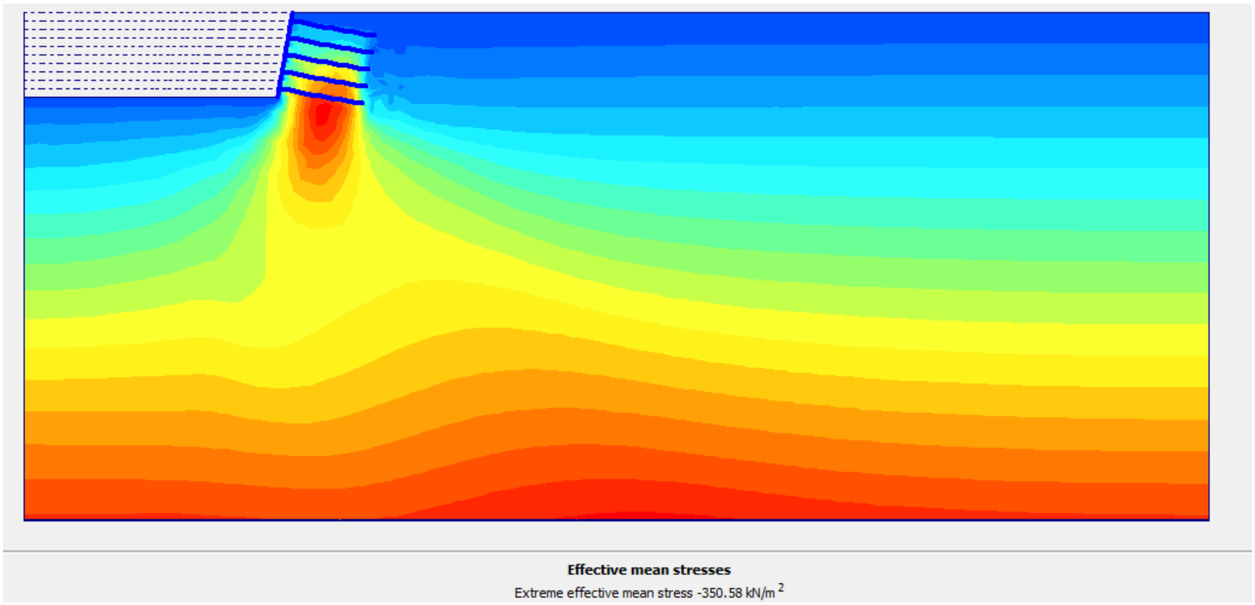

Fig 4. Effective mean stresses before excavation of soil nail wall with with β=i= 10 degree in loose sand.

TABLE VII. OUTPUT RESULTS FOR LOOSE SAND

Nail Inclination		**β=i=10º**				**β=i=30º**			
Nail length m	**Nail No from top**	**Max HD x10^{-3} m**	**Max AF kN/m**	**Max SF kN/m**	**Max BM kN.m/m**	**Max HD x10^{-3} m**	**Max AF kN/m**	**Max SF kN/m**	**Max BM kN.m/m**
5	1	-129.97	63.27	-1.01	103.5	-97.39	24.7	1.74	-127.63
	2	-118.46	107.12	1.24	-213.48	-97.57	86.47	2.48	-411.97
	3	-107.33	131.07	1.8	-297.98	-93.93	108.81	2.37	-379.7
	4	-102.66	158.91	2.77	-422.96	-88.49	120.85	2.83	-423.11
	5	-100	163.02	3.89	-565.72	-80.3	114.93	4	-577.42
4.5	1	-139.66	64.83	-0.48	-32.74	-96.96	-27.74	3.97	-154.89
	2	-125.44	100.89	3.06	-436.34	-98.29	89.19	2.07	-379.76
	3	-112.69	119.15	2.18	-327.571	-95.11	108.69	2.28	-402.35
	4	-104.26	153.43	3.5	-489.56	-89.56	121.8	2.85	-390.8
	5	-100	167.85	7.01	-652.57	-81.06	114.75	4.62	-604.25
4	1	-144.1	61.16	-0.69	-39.29	-98.63	-28.85	3.36	-198.63
	2	-129.79	102.53	4.07	-509.24	-101.16	89.14	1.67	-426.45
	3	-116.68	121.96	2.2	-307.27	-98.2	114.46	2.24	-424.43
	4	-108.51	148.05	3.97	-512.62	-92.25	120.11	2.82	-356.48
	5	-99.26	171.81	5.88	-725.09	-83.72	116.78	4.67	-599.48

Influence of nail length

The horizontal displacements are larger in top nails and reduce with the increase in depth of the nail from the top. The value of maximum horizontal displacement is higher at 4 m nail length and gradually decreases when nail length increases. This shows minimum wall movement occurs for 5 m and 4.5 m nail length when compared to 4 m nail length.

The axial force increases with increase in depth of the nail from the top. For β=i=10º, the maximum axial force are higher at 5 m nail length and then 4 m is higher than 4.5 m nail length. For β=i=30º, the maximum axial force are higher at 4m nail length and then 4.5 m is higher than 5 m nail length.

The shear force increases with increase in depth of the nail from the top. The nail having a length of 5 m had less shear force compared to the nail lengths of 4 m and 4.5 m. For β=i=10º, the maximum axial force are higher at 4m nail length and then 4.5m is higher than 5 m nail length. For β=i=30º, the maximum axial force are higher at 5 m nail length and then 4.5 m is higher than 4 m nail length.

The bending moment increases with increase in depth of the nail from the top. For β=i=10º, the maximum bending moment values are higher for 4 m nail length and gradually decreases when nail length increases. For β=i=30º,the maximum bending moment values are higher for 4 m nail length up to third nail whereas for fourth and fifth nail, 4.5 m nail length is higher.

E. Medium Dense Sand

The results obtained from different analysis by varying the different wall batter and nail inclination to horizontal (both being the same) and nail lengths for medium dense sand are presented in the table VIII.

Influence of wall batter angle β, and nail inclination to horizontal

For all nail length, the values of maximum horizontal displacement and maximum axial force are higher at β=i=10º than β=i=30º.The horizontal displacements are larger in bottom nails and decrease with the decrease in depth of the nail from the top.

The axial force values are smaller in top nails and increase with the increase in depth of the nail from the top. For β=i=30º the 1st nail has negative value, this indicates that the force is compressive.

Influence of nail length

The horizontal displacements are larger in top nails and reduce with the increase in depth of the nail from the top. For β=i=10º, the maximum horizontal displacement is higher at 4 m nail length than 5 m and 4.5 m nail length. For β=i=30º,

The highest value observed for 4.5 m nail length except the first and second nail.

The axial force increases with increase in depth of the nail from the top. For β=i=10º, the maximum axial force are higher at 4 m nail length and then 4.5 m is higher than 5 m nail length. For β=i=30º, the maximum axial force for first, fourth and fifth nail are higher at 5 m nail length and then for second and third nail values are higher at 4.5m nail length.

F. Dense Sand

The results obtained from different analysis by varying the different wall batter and nail inclination to horizontal (both being the same) for dense sand are presented in the table IX.

The values of maximum horizontal displacement and maximum axial force are higher at β=i=10º than β=i=30º.The

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horizontal displacements are larger in top nails and decrease with the increase in depth of the nail from the top.

The axial force values are smaller in top nails and increase with the increase in depth of the nail from the top. For β=i=30º the first nail has negative value, this indicates that the force is compressive.

TABLE VIII. OUTPUT RESULTS FOR MEDIUM DENSE SAND

Nail Inclination		β=i=10º		β=i=30º	
Nail length m	**Nail No from top**	**Max HD $x10^{-3}$ m**	**Max AF kN/m**	**Max HD $x10^{-3}$m**	**Max AF kN/m**
5	1	-58.41	37.84	-48.93	-21.91
	2	-51.84	75.19	-43.13	51.8
	3	-44.53	100.27	-38.93	66.4
	4	-39.24	112.36	-33.97	79.62
	5	-34.89	108.99	-29.08	80.1
4.5	1	-64.28	42.7	-47.52	-18.16
	2	-57.08	76.01	-45.1	58.25
	3	-48.97	103.05	-40.45	71.62
	4	-41.93	121.49	-34.95	76.97
	5	-37.33	119.74	-29.54	74.99
4	1	-68.77	44.5	-47.57	-19.3
	2	-60.65	79.17	-45.26	62.54
	3	-51.4	99.85	-40	69.92
	4	-44.11	117.54	-33.88	68.75
	5	-38.35	123.36	-28.2	65.98

TABLE IX. OUTPUT RESULTS FOR DENSE SAND

Nail Inclination		β=i=10º		β=i=30º	
Nail length m	**Nail No from top**	**Max HD $x10^{-3}$ m**	**Max AF kN/m**	**Max HD $x10^{-3}$ m**	**Max AF kN/m**
5	1	-28.58	9.02	-21.62	-30.34
	2	-24.9	48.67	-19.42	20.47
	3	-20.73	66.52	-16.26	34.53
	4	-16.62	82.59	-13.3	41.29
	5	-12.48	57.87	-10.39	31.83

G. Global Factor of Safety

The results obtained from different analysis by varying the different wall batter and nail inclination to horizontal (both being the same) and nail lengths for different density are presented in the table X.

TABLE X. GLOBAL FACTOR OF SAFETY FOR DIFFERENT SOIL DENSITIES

Nail length m	Nail No from top	Loose sand		Medium dense sand		Dense sand	
		β=i= 10º	**β=i= 30º**	**β=i= 10º**	**β=i= 30º**	**β=i= 10º**	**β=i= 30º**
4.5	1	1.38	1.23	1.65	1.62	2.08	1.92
	2	1.32	1.22	1.57	1.62	1.95	1.92
	3	1.26	1.32	1.58	1.52	1.95	1.87
	4	1.15	1.19	1.48	1.51	1.82	1.92
	5	1.19	1.25	1.47	1.61	1.83	1.98
4	1	1.34	1.25	1.623	1.55	2	1.94
	2	1.3	1.32	1.58	1.51	1.88	1.93
	3	1.21	1.38	1.49	1.51	1.9	1.85
	4	1.12	1.22	1.4	1.52	1.75	1.92
	5	1.08	1.21	1.36	1.54	1.69	1.91

For all nail lengths, density of the soil increases global factor of safety increases and depth of nail from top increases, it decreases. In case of batter angle, the first, fourth and fifth nail from top has higher global factor of safety at β=i=30º and in second and third nail there is a slight variations based on the density of the soil and nail length. If nail length increases, there is an increase in the global factor of safety.

H. Distribution of Axial Force, Bending Moment and Shear Force along the Nails

For loose sand the axial force distribution is tensile for all nails but for dense sand there is small variation in the axial force distribution for first nail only. For both loose sand and dense sand the maximum axial force mobilized towards the face of nailed soil wall as the depth increases. The maximum axial force points along the different nails are traced and the distance from the face are listed in table XI and table XII.

TABLE XI. MAXIMUM AXIAL FORCE POINTS ALONG THE DIFFERENT NAILS

Nail number	Axial force for 10º in kN/m	Axial force for 30º in kN/m
N1	63.27	9.02
N2	107.12	48.67
N3	131.07	66.52
N4	158.91	82.99
N5	163.02	57.87

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TABLE XII. HORIZONTAL DISTANCE FROM FACE FOR LOOSE SAND AND DENSE SAND

Nail No.	Max HD x10^{-3} m for β=i=10°	
	Loose sand	Dense Sand
N1	3.14	0.64
N2	2.52	0.64
N3	2.52	0.64
N4	2.52	0.64
N5	2.51	0.64

From the table XII, we observed that, the horizontal distance from face for loose sand is greater than dense sand. These also indicate the change in the critical failure surface for nailed soil wall at different density and are shown in Fig 5 and Fig 6.

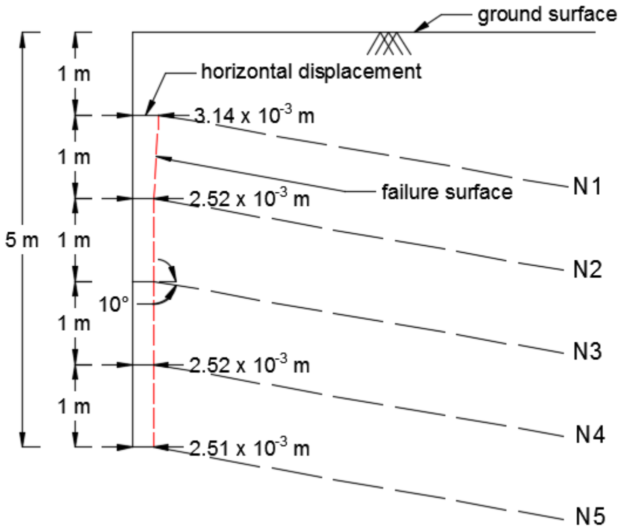

Fig 5. Horizontal Displacement from Face for Loose Sand

The critical failure surface are also traced for other batter angle and nail inclination for both loose sand and dense sand. The influence of batter angle and nail inclination are negligible for the different density of sand. For higher batter angle and nail inclination, the nails are subjected to compression at their rear ends. The compression zone increases as the depth and inclination (β & i) increases. The difference in the behavior is different due to dilation of dense sand. For all nails irrespective of the density, inclination the bending moment and shear force are almost maximum at the face of the nailed wall. The distribution of bending moment and shear force depends upon the vertical loading on the nail and the support conditions. The support conditions of all the nails are almost fixed. At the face of nail is fixed in a steel plate for the design punching load and at the rear end it get anchored in the passive zone.

The maximum permissible tensile stress of nails is 200MPa. The permissible shear and bending stress is also 2000MPa as per IRC: 21-2000. The permissible compressive stress is 170MPa. For 20mm nail the permissible axial force is 62.83 kPa.

The mobilized axial forces are relatively higher for loose sand because the horizontal displacements are higher in loose sand than dense sand. The axial force exceeds the permissible limits both in loose and dense sand. The difference is higher for loose sand than in dense sand. Since axial force are exceeding the permissible limit the bending stress and shear stress also exceeds the permissible limit. Even though all these nail design parameters exceeds the permissible limits, the global factor of safety of nailed wall in greater than 1.

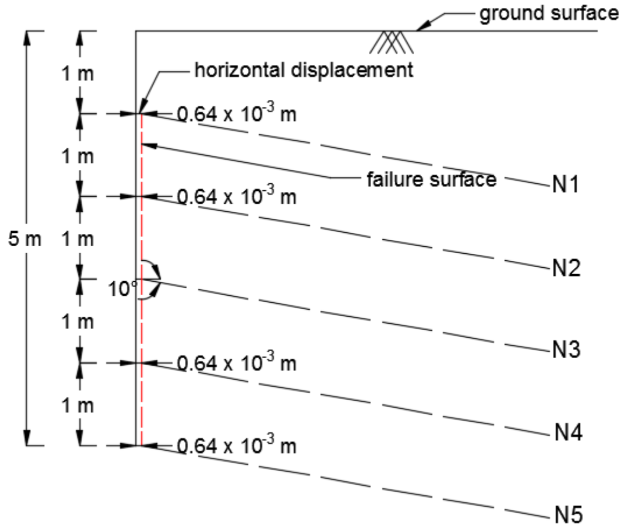

Fig 6. Horizontal Displacement from Face for Dense Sand

The simplified wedge analysis were also done for the nailed wall with batter angle of 10 degree for loose sand condition and the factor of safely in 0.33 inclination of nails increased the global factor of safety to 3.1. The global factor of safety obtained for the same case using PLAXIS 2D.

From the analysis we concluded that, the Horizontal Displacement is maximum in the first nail which decreases as the depth of the nail from the top of the wall decreases. The maximum Axial Force is located near the critical failure surface. The point of maximum Axial Force in any nail move towards the facing as the depth of the nail decreases. The Shear Force and Bending Moment are found to be higher at the facing.

VI. CONCLUSION

Numerical analysis using software PLAXIS 2D were carried out by varying density of sand, batter angle, nail inclination, height of wall. The important observations made from this study are briefed below.

A. Influence of density of sand

For all the batter angles, the horizontal displacement is found to be maximum in loose sand, followed by the medium sand and then dense sand. The maximum horizontal displacement is found to be large is wall having β=i=10o than those with β = i = 30o. The shear force and bending moment are maximum in loose sand followed by medium dense sand and then by dense sand. The axial force is lowest in dense sand on the contrary. Factor of safety is high in the case of dense sand (nearly 2.0) followed by medium sand (1.60). The factor of safety is the lowest in loose sand (1.3).

B. Influence of wall batter angle β, and nail inclination to horizontal

In walls having β = i = 30o we found that the amount horizontal displacement is more or less same. But in walls having β = i = 10o, large amount of displacement is observed. The axial force is found to be maximum in walls having β = i = 10o than walls having β = i = 30o. The shear force & bending moment are found to be lowest for walls having β=i=10o and increase with increase with β = i. The factor of safety is the lowest for β = i = 10o compared 20o& 30o the difference very minimum.

C. Influence of nail length

In all cases of batter angles (β=i) and densities of sand, the results of the analysis show only slight changes in behavior for the changes in Nail Length was observed 4 m being was critical. The length of Nail taken for analysis is 1.0H, 0.9H & 0.8H. Since no significant difference could be arrived, the further analysis could be conducted for nail lengths 3.6H & 0.7H to find the optimum nail length required.

VII. REFERENCES

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