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Micro-Pile Foundation for Avalanche Retaining Barriers

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Introduction

Avalanche hazard can be mitigated with the help of retaining barriers. These barriers are installed in the formation zone having slope between 30^o and 50^o. They sustain or retain the snow-mass on uphill side. These supporting structures are designed basically for the static forces produced due to creep, glide and settling of snow pack. Snow nets serve as retaining barriers by adjusting their supporting plane with the increasing depth of snow with a view to control the snow forces.

Design forces acting on snow nets have been worked out by Chaudhary and Mathur, 2004. Snow force is exerted at point ‘C’ to the tune of 153 kN (T_1) on uphill foundations and at point ‘A’ 52 kN (S) on downhill foundations (Figure 1). Isolated footings have been made at point ‘C’ and ‘A’ on inclined terrain to withstand the tensile forces coming due to snow.

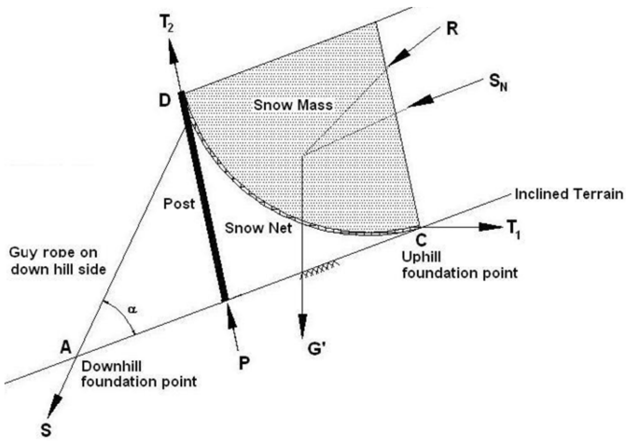

Fig 1: Snow Forces Acting on the Snow Nets

In the severe winter of 2004-2005, the shallow foundations posed the problems of dislocation, uprooting and overturning because of high magnitude of

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snow pressure and erosion of surrounding soil. It was decided to design a micro-pile at point ‘C’ for 310 kN uplift force considering two fold factor of safety.

In the absence of the results on uplift capacity of model concrete pile, shaft resistance of soil in uplift under pressure grouting, construction of bore pile on an inclined slope and mode of failure surface, full scale concrete bored cast in-situ micro-piles were made for testing in uplift. Field test results of long micro-pile with different slenderness ratio, λ are presented in the paper.

Review of Previous Work

Ireland (1957) conducted six field pullout tests on Raymond step-taper piles embedded in sand along the coast of Florida. Based on his experimental results, Ireland has suggested an average value of K_s to be equal to 1.75. Extending the work of Meyerhof & Adams (1968) on uplift capacity of footing, Meyerhof (1973) introduced an uplift coefficient, K_u in place of K_s. The theory assumed failure along the pile-soil interface and showed that the pullout capacity for batter piles in sand increases due to an increase of the inclination angle,α, of the pile with respect to the vertical. Awad & Ayoub (1976) showed that the pullout capacity of these piles decreases due to an increase of the angle,α. Ismael & Klym (1979) reported value of ‘K_u’ worked out as 1.6 and 2.1 for K_c in case of full scale cylindrical pier. The test showed an increasing trend of K_u (varying from 0.5 to 2) with the N value**.**

Das (1983) performed a laboratory test in cohesionless soil where the ultimate uplift capacity is predicted from its results. According to him the unit skin friction (f_s) increases in almost a linear manner up to a certain depth and remains constant thereafter. The experimental results reported by Afram (1984) showed no significant change in the pullout capacity of batter piles due to an increase of the pile inclination. Ismael & Al-Sanad (1986) reported the average value of K_u as 1.05 for short piles ($\lambda \sim 20$) in calcareous soils having a carbonate content of 10-30 %.

Chattopadhyay & Pise (1986) proposed an analytical method to predict the ultimate uplift capacity of piles embedded in sand and assumed that during uplift of the pile, an axisymmetric solid mass of soil is initiated to move up with pile. Hanna & Nguyen (1986) confirmed the observation of Awad and Ayoub (1976) for the shaft resistance of single piles subjected to compression loading. Swiss guidelines (1990) reported the permissible tensile force as a function of anchor length and soil features. Margreth (1991) gave a brief of permissible tensile forces and anchor piles details for Snow bridges. Margreth (1997) tested the micro piles for axial force as well as lateral force and compared experimental values with Swiss guidelines (1990) which were lowered by a factor of two. Ho et al. (2002) conducted field test on bored pile embedded in jet grout layer and observed that influence of the grout layer was pronounced for piles under compression loading compared with uplift loading. Hanna & Sabry (2003) presented a theoretical model to support that the pullout capacity of a single pile in sand decreases, remains constant or increase due to an increase of the pile inclination,α, for loose, medium and dense sand respectively. Dash & Pise (2003) found from experimental results that the presence of the compressive loading on the pile decreases the net uplift capacity of the pile. Shanker et al. (2006) adopted the same assumptions as proposed by Chattopadhyay & Pise

(1986) and introduced another factor 'C' in the expression equal to 1.9 as worked out from experiments.

Micro - Pile Construction and Testing

One of the typical avalanche prone site known as MSP-4 has been selected on new alignment to proposed Rohtang tunnel between Solong (Km 13 from Manali) to Dhundi (Km 20 from Manali). Average slope of the site is varying from 28^o - 32^o. Cast in-situ concrete piles have been made because of ease in construction, transportation of drilling machine and construction material, and able to take high magnitude of uplift forces. Three different length of piles, i.e., 3.5 m, 5.0 m and 6.5 m having 100 mm bore hole size were selected for field trial. Hydraulic rig with core bit size 98.79 mm was used for making bore hole in the field. Anchor bolts of size 32 mm diameter tor bar of respective depth have been provided in the bore hole. Stabilizing tube made up of perforated tube of size 76 mm has been provided throughout the length of pile (Figure 2). The aim of providing the tube was to clamp the pile in position and to avoid chances of collapse of over burden strata. Upper portion of micro-pile acted like a prop and lateral load carrying capacity can be increased significantly. Concrete of ratio 1:1:2 was used in bore hole and cement slurry mix of 1:1 was injected with the help of triplex pressure pump at 93 kN/m^2 pressure for 3.5 m pile, 123 kN/m^2 pressure for 5.0 m pile and 145 kN/m^2 pressure for 6.5 m pile. Grouting has been done as per IS 6066 (1994) using pressure approximately 25 kN/m^2 per m of overburden. All piles were made at an inclination of 30^o to 45^o from vertical axis on 30^o inclined terrain of mountain. Pull out tests have been conducted with the help of central hole jack of 50 tonne capacity on 09 different micro-piles as per IS: 11309 (1985). Cross section of micro-piles is shown in Figure 3.

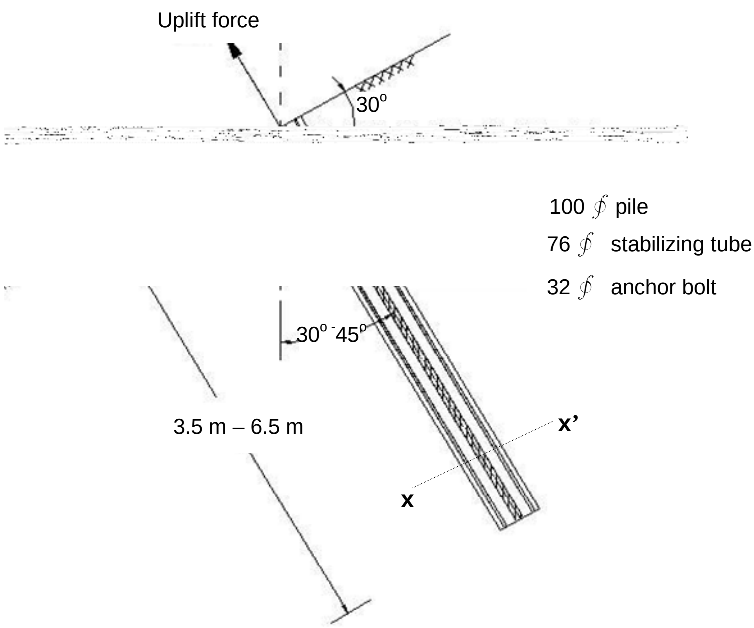
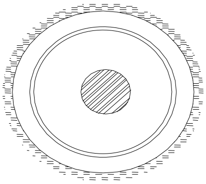


Fig. 2 Micro-pile on Inclined Slope



Cement concrete 1:1:2

hard soil. Test conducted as per IS 4968 (1976) with cone of 60 degree and 50 mm diameter was driven continuously into the ground by the blows of a standard 63.5 Kg hammer falling freely through a height of 75 cm. Various laboratory tests have been conducted to work out the engineering properties of the soil. Bulk density is varying from 1.67-1.73 g/cc, angle of shearing resistance varying from 31 to 33^o (determined in laboratory by using direct shear test), natural moisture content varying from 7.2 to 8.2%, porosity varying from 27 to 30%, specific gravity varying from 2.67 to 2.7, Poisson's ratio 0.34 to 0.44 (determined from cylindrical rock specimen of 54 mm diameter core in compression as per IS 9221:1979) and SPT 'N' values higher than 100.

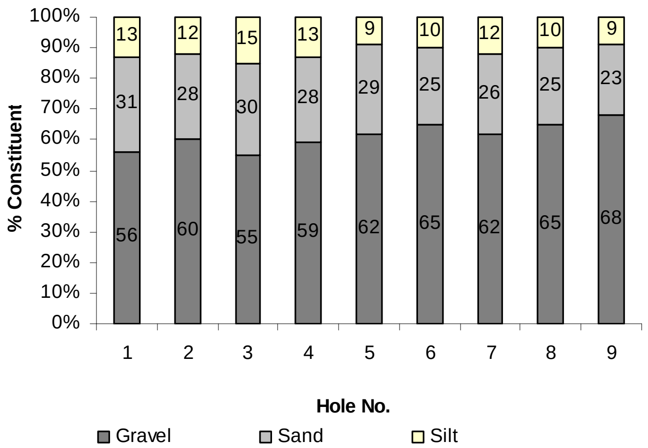


Fig. 5 Soil Composition of Hole Nos 1 to 9 in MSP-4 Avalanche Site

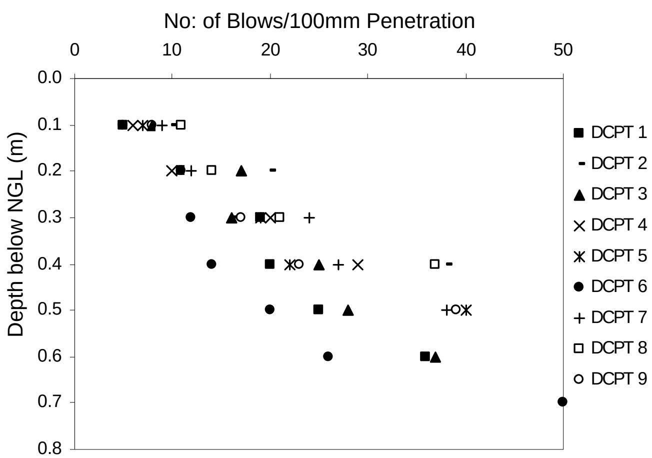


Fig. 6 Dynamic Cone Penetration Test of Hole Nos 1 to 9 in MSP-4 Avalanche Site

Results and Discussion

The plot of applied uplift load on micro-pile versus uplift displacement during the pull-out tests are shown in Figure 7(a), (b) & (c). The ultimate resistance of single piles under axial pull has been taken as the load at which piles move out of the soil. In such conditions the axial pull versus movement curves become parallel to the displacement axis and maintains continuous displacement without any further increase in pull (Meyerhof 1973; Chattopadhyay and Pise 1986). Ultimate uplift capacity is about 82 kN for 3.5 m micro pile, 250 kN for 5.0 m pile and 465 kN for 6.5 m pile. These micro-piles fail at an interface of pile shaft and soil strata.

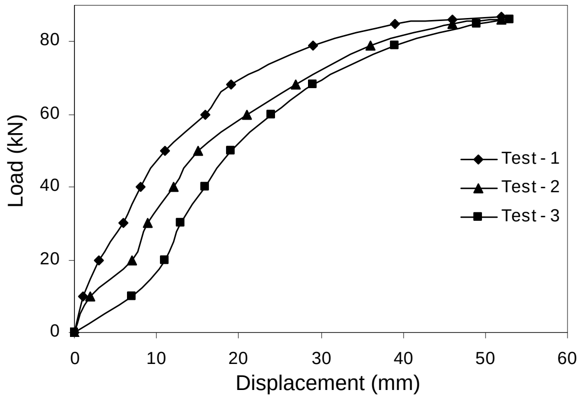


Fig. 7 (a) Uplift Force v/s Uplift Displacement Obtained during Pull Out Test for 3.5 m Long Micro Pile

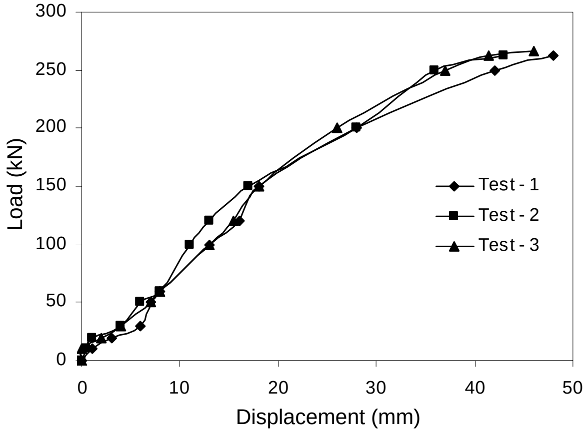


Fig. 7 (b) Uplift Force v/s Uplift Displacement Obtained during Pull Out Test for 5.0 m Long Micro Pile

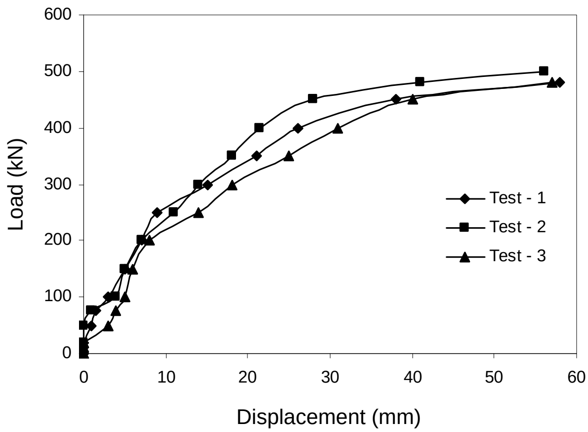


Fig. 7 (c) Uplift Force v/s Uplift Displacement Obtained during Pull Out Test for 6.5 m Long Micro Pile

To investigate the significance of the additional skin friction resistance contributed by the pressure grouting, an estimate of the average skin friction of the embedded pile length corresponding to each load increment during uplift was determined by using the expression, $f_{si} = Q_{si}/ \pi d.L'$ where Q_{si} is uplift force applied at respective load increment, L' is embedded pile length below the ground [i.e., $L' = L- L_o$] and plotted against uplift displacement as shown in Figure 8.

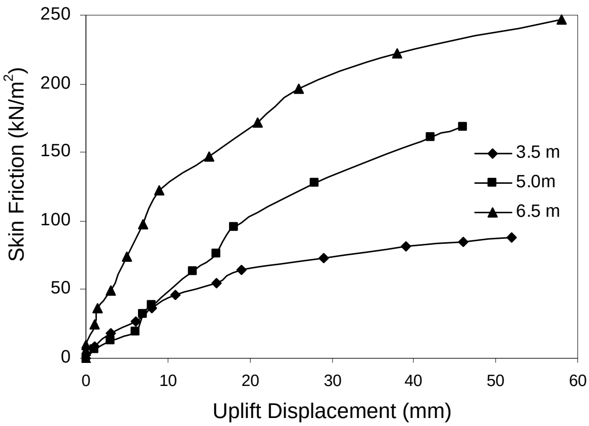


Fig. 8 Skin Friction versus Uplift Displacement

It may be noted that at failure the curve becomes parallel to uplift displacement axis. During pull out test, failure took place at the interface of pile shaft and surrounding soil strata. Pile moved out of the soil. There is no change in diameter of pile shaft. Uplift displacement of micro-piles mobilizes the ultimate resistance in a narrow range of 40-55 mm which is about 40-55% of pile diameter whereas Shanker et al. (2006) and Ismael & Klym (1986) reported that pile displacement required to mobilize the ultimate resistance found to be 2-5 % and 5-10 % of pile diameter respectively considering model piles made of mild steel rod and embedded in sand with $\lambda \leq 30$. Friction resistance/ bond strength between pile shaft and soil strata depends on pile length, type of strata available, its thickness and formation of soil nailing in the voids of soil. It is found that friction resistance/bond strength is approximately 80 kN/m^2 for 3.5 m pile, 164 kN/m^2 for 5.0 m pile and 234 kN/m^2 for 6.5 m micro pile (Figure 9).

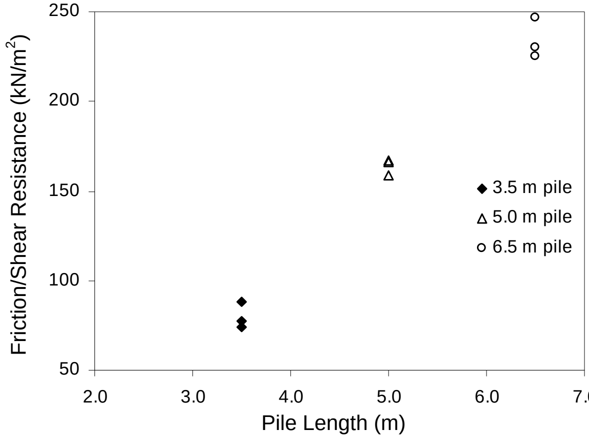


Fig. 9 Friction/Shear Resistance versus Pile Length

A plot of dimensionless load factor [Q_u/ (½.π.d^2. γ.L)] against λ is shown in Figure 10 for a particular site condition with γ (= 1.67-1.73 g/cc) and ϕ (= 31 to 33°).

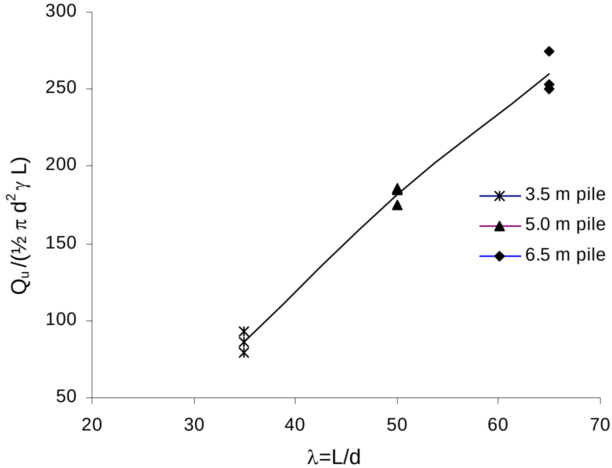


Fig. 10 Uplift Coefficient versus Slenderness Ratio λ

Slope of the curve gives the value of ($K_u.\tan\delta$) which is a constant value showing a straight line trend. It was drawn to observe the effect of uplift coefficient with depth of pile. Value of ($K_u.\tan\delta$) is about 2.46 for 3.5 m, 3.63 for 5.0 m and 4.0 for 6.5 m micro-pile. This higher value is due to injection of cement grout under pressure which modifies the value of skin friction as well as angle of friction. Injection of cement grout under pressure not only fills the voids but also set with time, binds the soil grains together, thereby, increasing the ultimate uplift capacity manifold. It causes fracture of the soil, deep penetration of grout mix inside the voids of soil and increase in its macroscopic strength. Root like branches formed inside the soil strata which acts as soil nailing. These nails transfer the tensile force over the entire length of pile in the surrounding soil to a great extent.

A plot between ultimate uplift capacity versus λ (35, 50 & 65) is shown in Figure 11 which increases exponentially with bore hole depth and the trend of measured uplift capacity are similar with Margreth (1991).

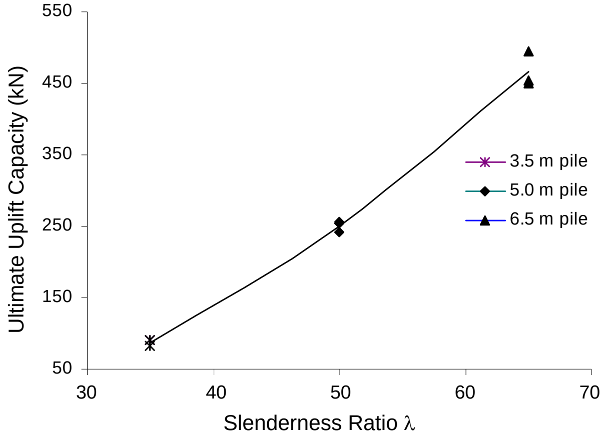


Fig. 11 Ultimate Uplift Capacity versus Slenderness Ratio λ

The results obtained from pull out test conducted on full scale micro-piles are compared with the earlier theories in Table 1. Most of the previous studies are based on laboratory test conducted on model pile with slenderness ratio less than 30 which is made of metal and embedded in the sand. The measured values of ultimate uplift capacity vary between 37-61 % both for Ireland (1957) and Meyerhof (1973) while variation of these values is in between 52-80 % in case of Chattopadhyay & Pise (1986), and 34-73 % in case of Shanker et al. (2006). Such a large variation (Figure 12) is due to the fact that piles achieve substantial uplift capacity due to increased value of skin friction and coefficient of uplift coefficient under the influence of pressure grouting. Minimum variation between 19-26 % is found in case of Hanna & Sabry (2003). These findings appear to be in agreement with recommendation of Hanna & Sabry wherein earth pressure distribution around pile shaft taken into account in addition to angle of friction between pile's shaft and soil.

Measured values of ultimate uplift capacity for 5.0 m and 6.5 m micro-piles are in reasonably good agreement with the ultimate uplift capacity as suggested by Swiss guideline (Figure 13). Measured values for 5.0 m pile are 16 % lesser and 6 % higher in case of 6.5 m piles. Swiss guidelines suggest a safety factor of two because of uncertainty like correct estimation of soil features, bonding between soil & grout, crack in the soil, risk of damage to structures, anchor position in bore hole, etc. Ultimate uplift capacity of 3.5 m pile is lesser as compared to the values of Swiss guidelines. It lies very close to the permissible uplift capacity as suggested by Swiss guideline. The difference in the results was due to lesser grout pressure applied in a bore hole. The authors' are working on type of grout mix, which was different in case of Switzerland and permissible pressure required for injecting the grout mix deep inside the pores of the soil.

Table 1 Measured and Predicted Ultimate Uplift Capacity

Slenderness ratio L/d= λ	***Ultimate Uplift Capacity kN***					
	Ireland (1957)	Meyerhof (1973)	Chattopadhyay & Pise (1986)	Hanna & Sabry (2003)	Shanker et al. (2006)	Measured (present study)
35	52.13	52.13	39.92	98.49	51.35	82.81
50	106.82	107.55	61.19	201.42	87.17	250.52
65	180.90	184.68	92.12	340.79	124.43	465.08

Diameter of pile, d =0.100 m, Angle of shearing resistance, ϕ = 32°, Angle of wall friction, δ = 24°, Soil density, γ = 17.6 kN/m³

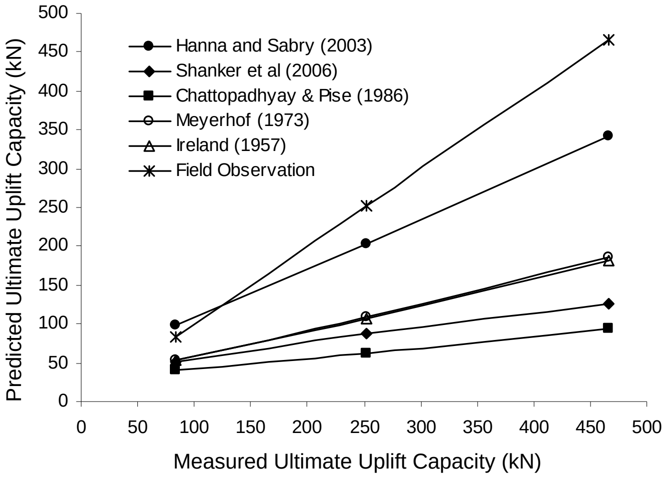


Fig. 12 Comparison between Measured and Predicted Ultimate Uplift Capacity

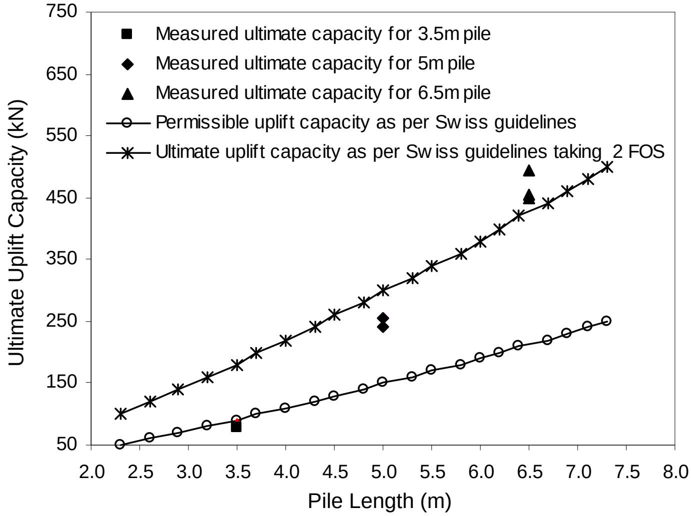


Fig. 13 Comparison Between Measured Ultimate Uplift Capacity and Swiss Guideline Values

Conclusions

In present study, it has been observed that the presence of pressure grout can have a significant influence on pile performance in terms of increased uplift coefficient, skin friction and bond strength which are summarized as under based on studies reported above :

1. It is found that values of uplift coefficient are higher than two. Generally values are lower than two as mentioned in review of previous work.

2. Observed values of bond strength in case of 5.0 and 6.5 m pile are comparable with anchoring of piles in rock. In case of rock, bond strength is varying from 150-300 kN/m^2 in weak weathered chalk, mudstone and shale as per Tomlinson & Boorman (1995).

3. This type of pile offers maximum resistance against pull. Uplift displacement of pile to mobilize the ultimate resistance is in the range of 40-55 mm which is about 40-55% of pile diameter.

4. Micro-pile of 5.0 m length provides substantial uplift capacity with little higher injection pressure in case of proposed snow nets. Pile of this length seems to be a technically feasible solution for avalanche retaining barriers. It will avoid all the shortcomings of shallow foundations as discussed in introduction.

Notations and Symbols

The following symbols are used in the paper:

C	Constant
d	Diameter of pile
f_s	Unit skin friction
f_{si}	Average skin friction of embedded pile length corresponding to each load increment
G'	Weight of the snow prism
K_c	Coefficient of lateral earth pressure in compression
K_s	Coefficient of earth pressure
K_u	Uplift coefficient
L	Length of pile
L'	Embedded pile length below the ground
L_o	Pull out displacement or length of pile exposed during pull out test
N	SPT values
P	Axial force in the Swivel Post
Q_{si}	Uplift force applied at respective load increment
Q_u	Ultimate uplift capacity
R	Resultant force
S	Tension in down hill anchor at point A
S_N	Component of snow pressure parallel to the slope per unit length
T_1	Tension at point C
T_2	Tension at point D
α	Pile inclination with respect to the vertical axis
δ	Angle of wall friction
γ	Soil density
λ	Slenderness ratio
ϕ	Angle of shearing resistance

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