Micro Piles as a favorable foundation alternative in Ropeway-Engineering

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Standing at the step to the third millenium also ropeway engineering has to contribute to the changes and developement.

In countries, where already lots of ropeway systems are installed – especially Europe with Austria, France, Italy and Switzerland as well as North America with the USA and Canada – investments in the renewal of the old systems will save the future of wintersport resorts. When renewing in most cases the new systems grow bigger – transportation capacity as well as comfort for the user have to be optimized.
When planning new systems in many cases environmental impost are severe and cause high costs.

Whilst the investors are looking for a reasonable cost – profit relation, the environmental organizations are looking for solutions, which show less influence on nature. As these demands are often diametral, it is a challenge for every engineer to produce a cost saving and nature caring project. A wide range of work is waiting for ropeway engineers and good ideas - technical and economical - are called for.

As with the new bigger systems – coupling 4- to 8-seat lifts, coupling gondolas with up to 24 persons capacity, cablecar systems – and with the necessity to store the gondolas, seats etc. the costs of buildings and pillar-foundations grow the same ratio as the buildings and foundations do and now may take up to one third and more of the total costs of investment.

This is the reason, why this part has to be worked out more carefully than in former times, when foundations had been smaller and environmental imposts not that severe. In Europe waste management causes very high costs when removing old systems, therefore thougths on reusing old parts – foundations – should be on top of engineering work, when changing the ropeway system.

In many cases the old foundations are in good condition and can be used again.
Due to the higher loads of the new systems this is not always possible without alteration or reinforcement. The old foundation has to be upgraded to be able to take over the new, higher loads, which can be done by using micro-piles.

The use of piles in foundation engineering is out of discussion and known as a cost saving alternative as well as the only solution to solve founation problems in many parts of civil engineering. In ropeway engineering, foundations seem to be usually a minor problem to be discussed and worked on and often neglected by ropeway engineers. In many cases this problem is moved over to the investor, who has to solve this problem on his own.
In the following presentation I will show a way , which has proved in a varity of projects to be a favorable alternative to solve foundation problems in a cost saving and technical outstanding way.

Micro piles

When building in mountain areas, the connection to roads on which building material can be transported is one of the main logistic problems to be solved. Either due to restrictions of environmental groups or geological difficulties, roads cannot be bulit, so all material for the erection has to be transported either by helicopter – a rather costly way – or by a transportation ropeway erected for the time of building the new system. In all cases transport of building material should be minimized to cut down costs. Also the use of huge machines for the erections cannot be realized due to the lack of roads with the necessary load capacity.

The other part is the the kind of underground, on which the foundations have to be realized – in many cases big stones, creeping instable slopes, soft soil, rock and even ice make the choice of usable foundation systems smaller and smaller.
Another important point is the adaptibility of the chosen foundation-system to the underground on the site, because changes raise costs.

All these points are fulfilled by *micro piles – injection piles*, which can be drilled by small machines nearly erverywhere a helicopter or a transportation-cable car can put lightweight drilling equipment down. Due to the modern drilling equipment neither stones and rocks nor ice are obstacles when drilling the piles. The piles are drilled with tubing or without in rock or ice, where drilling holes can be produced without problems. In loose soil drilling is done with tubing. Into the drilled hole, which has a diameter of minimum 100 mm, a reinforcement bar – diameter 32 to 50 mm ribbed steel BSt 500S or steel S 555/700 when using diam. 63,5 mm – is inserted and afterwards the hole is filled with cement-mortar under pressure-control. To improve bearing capacity the possibility of a secondary injection can be provided. Corrosion protection is provided by cement mortar in cases of short term use, by cement mortar and syntetic products.

Internal bearing capacity

The internal bearing capacity of a micro-pile depends mainly on two factors.

1. reinforcement bar diameter
2. drilling hole = mortar body diameter.

The so called GEWI-pile by Dyckerhoff Systems International will be discussed in the following, which has got an admission by the German Institute of Bautechnik, Berlin. With the drilled micro pile a usable bearing capacity up to 1172 kN/single pile and 1963 kN/triple GEWI 50 can be reached in accordance to the length of the pile and to soil.

Tab. 1 internal bearing capacity

time of usage				**loading case 1-3** DIN 1054			
				Pressure		pull	
< 2 years standard corrosion protection				1	2 and 3	1 to 3	--
> 2 years standard corrosion protection				1	2 and 3	2 and 3	1
</>2 years double corrosion protection				1	2 and 3	1 to 3	--
	bar diam.	Steel parameters		Bearing load			
		A_s	$F_s=A_s*b_s$	$F_s/1,71$	$F_s/1,50$	$F_s/1,75$	$F_s/3,03$
	mm	Mm^2	kN	kN	kN	kN	kN
GEWI-pile	32	804	402	235	268	230	133
	40	1257	628	367	419	359	207
	50	1963	982	574	654	561	324
	63,5	3167	1758	1028	1172	1004	523
GEWI-multiple pile	3*32	2412	1206	705	804	690	399
	1*40+50	3220	1610	942	1073	920	531
	3*40	3770	1885	1102	1257	1077	622
	2*50	3927	1963	1148	1309	1122	648
	2*40 + 1*50	4477	2238	1309	1492	1279	739
	1*40 + 2*50	5184	2592	1516	1728	1481	855
	3*50	5890	2945	1722	1963	1683	972

Load case 1 – permanent loads, regularily occuring traffic loads.
Load case 2 - load case 1 plus not regularily occuring traffic loads at same time
Load case 3 – load case 2 plus exeptional loads at same time

External bearing capacity

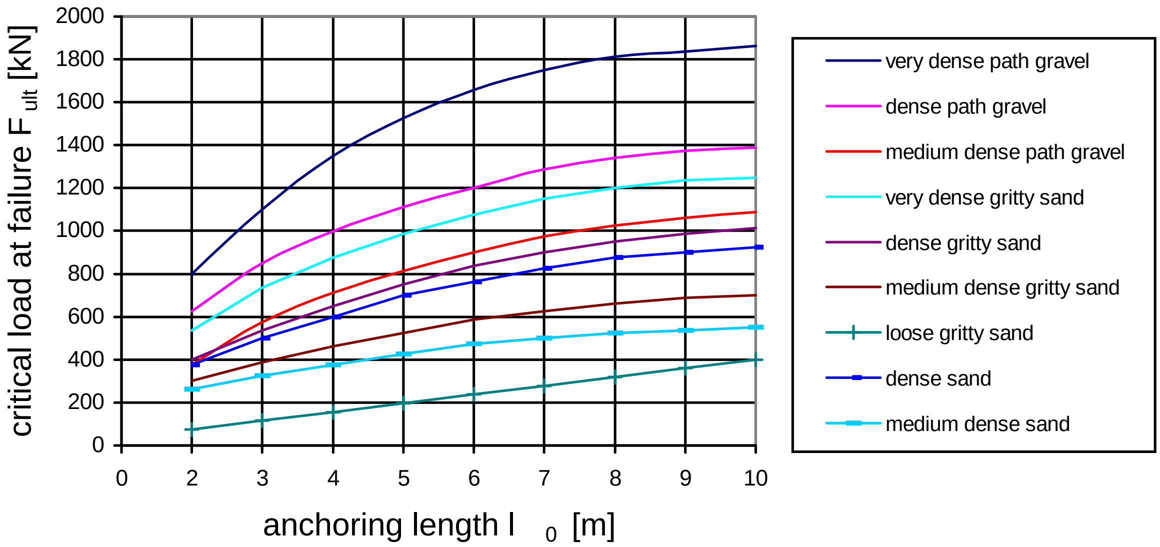
After the soil investigation, the friction coefficient between cement-mortar injection and surrounding soil can be fixed and the length of the pile can be chosen.
The length of the piles is equivalent to the length of injection-anchors in bearing soil, if the usual injection technique is provided at the pile-production.
For a preliminary calculation, the numbers and values in the following charts and diagrams can be used, which have to be proven by pile-bearing-tests.
For selected soils the limits of friction-capacity can be taken out of table 2, a security-factor of at least 2 has to be used. As these figures are rather low, pile-tests should be made to provide a cost saving solution.
Piles can be used for foundations with alternating-loads as well as for bearing- and tie-loads.

Tab. 2 – limits of friction for injection-piles – DIN 4128

Soil	**Bearing-pile MN/m²**	**tie-pile MN/m²**
gravel	0,20	0,10
Sand – gravel	0,15	0,08
Cohesive soil	0,10	0,05

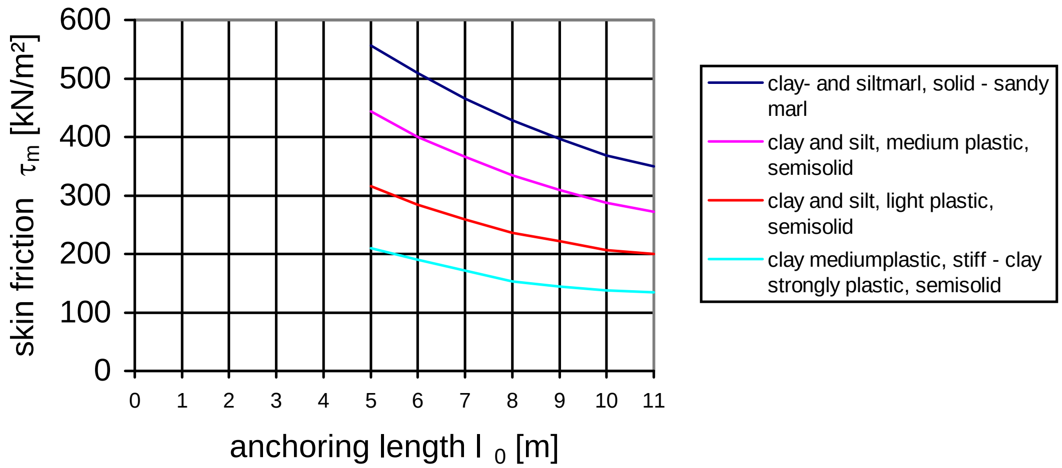
The following diagrams show minimum anchoring-lengths of micro-piles in non-cohesive and cohesive soils *(Ostermeyer).*

Picture 1 – empirical values of anchoring-lengths in non-cohesive soil



The first diagramm shows the lengths at the critical load for path gravel with U=5-33, gritty sand U=8-10, medium and coarse sand U=3,5-4,5 and fine and medium sand U=1,6-3,1.

Picture 2 – empirical values of anchoring lengths in cohesive soil with reinjection.



Calculation

When calculating pile foundations the following items have to be mentioned and should be thougt of by every engineer.
Piles preferably should be used to take axial loads.
In many or most cases it cannot be avoided that piles get also non-axial loads – horizontal loads. These horizontal loads are divided in active and passive horizontal loads on piles. An active load is a planned load, directly on the pile, coming from the construction above, a passive is a load caused by landfill, soil and non planned horizontal loads on the piles beneath surface.
In soft soils and ice the soil and ice ”flows” around the pile and causes a bending load. In stiff or hard soils, which are creeping or sliding like a block, the pile can work as dowel and is mainly charged by shear. In this case even mirco-piles can even help to stabilize a slope.

Depending on the situation of the foundation element, which is supported by the piles, we speak of a high or low pile-foundation grille. With a low pile-foundation grille the foundation element is bedded on the soil and piles are hoizontally bedded – even in soft soils the pile gets horizontal beddig and buckling does not have to be calculated. As a limit of soft soil can be assumed a soil with an undrained shear-strength of $c_u \geq 0{,}01$ MN/mm². When using a high pile-foundation grille also the buckling strength of the piles has to be checked. This case will occur, when working on foundations on glaciers or with very soft soil or using piles in sliding or creeping slopes.

As main parameters for the calculation the following items should be obeyed:

- Head construction works like a block – stiffness much higher than piles
- Bearing soil layer is immobile

- Piles are jointed at the top and on bottom in the soil.
- Piles are linear-elastic
- Piles work as single piles – not coupled
- Pile-load is mainly axial
- Pile force has to be burdened to foundation element
- Transmission length of reinforcement bar in concrete

Pile calculations can be schematized very easily, so these calculations can be written in a program calculating the deflections, torsions and pile-forces.
The three main steps of a pile-grille calculation are

1. Calculation of geometric data of pile-grille
2. Calculation of stiffness matrix of the foundation system
3. Solution of equation system and calculation of pile-forces and deflections

In ropeway engineering loads in pillars are usually symmetrical, so piles should also be placed symmetric in both directions.
When using pile foundations with stations, piles usually are placed symmetric to the ropeway axis. This makes calculation work easier.

Buckling calculation may be important when working with long piles standing on rock, which have been drilled either through soft clay or ice, as they are never drilled straight. In ice and soft soil the load of flowing ice or creeping soil has to be calculated as additional bending load on the piles.

A big advantage of micro-piles is the possibility to take up tensile forces, which cannot be done by a shallow foundation. This makes a pile-foundation an ideal foundation for excentric loads or momentum forces occurring with pillar foundations caused by assymetric loads such as wind etc., or with foundations situated in creeping slopes, where the steel pillars have to be shifted to alingne them again after a while.

As steel reinforcement bars used with micro-piles are not that very high quality steel as used with anchors, steel is also less influenced by corrosion and mechanical injury, creating long-lasting elements in our foundation.
When tensile strenght in the reinforcement bar is bigger than 165 N/mm^2 the corrosion system consisting of syntetic materials has to be used.

Mortar can be adapted by using special types of high quality cement to be resistant against sour water and sulphat attack.

When using a pile-foundation, the lengths shown in the diagrams above should only be used for a precalculation. For the detailed calculation pile-tests, in which settlement under vertical load is measured have to be made, to get realistic bearing capacities.

Examples of executed foundations

The following examples show the possibilities of pile-foundations used with ropeway engineering in the past years since 1991.

- Already in 1991 the foundation of a coupling 4seat system was carried out with the use of micro-piles. The platform above the garage for the seats is used as waiting area. In winter huge run-preparing machines have to pass and in summer it shows a green meadow, where cattle grows. As the station is situated in a rather steep instable slope, the foundation of the pillars of the garage – load about 4000 kN/foundation – was executed with 4 micro-piles, each with length of 10 to 15 m. Pile-tests showed a load capacity of 2000 kN/pile at a settlement of 12 mm. For calculation the pile-load was fixed with 1000 kN. Compared to the small block of b/l/h = 150/150/100 cm the conventional shallow foundation would have had blocs of 400/400/150 cm, which could not be carried out due to to the steep and instable slope in the foundation area.

- In 1994 another station of a coupling seat system was situated on a landfill with a height of nearly 8 m, which has been put there about fifteen years ago. To secure a stable foundation, micro piles with a length of up to 15 m were drilled – seven for the whole station. The comparison with the costs for a conventional foundation with heavy-weight concrete blocs showed an advantage of about US$ 15 000 for the micro-piles. The site was only accessable by a material ropeway down from the top of the mountain, so drilling equipment had to be lightweight.

- In 1997/1998 the change of an old double-seat chairlift to a coupling six-pack was planned in St. Anton am Arlberg in advance to the Ski World Championships in 2001. On the same track using the old foundations the new system has to be realized. As loads were much bigger – especially momentum grew to wider span of the pillars – a solution had to be found to fulfill the investors wishes of a cost-saving erection. As waste costs of the old concrete-blocks would have been rather high – the demolised concrete would have had to be brought down to the valley – the old foundations had to be reused. With four micro-piles the old foundations were enhanced to be able to take over the bigger loads. To adapt the head of the foundation for the new steel-pillars and to be able to take over the load from the foundation a partly new head was realized at five of the 12 pillars. The site could only be reached by material-ropeway with a bearing capacity of maximum 5 tons, so the drilling equipment had to be leigthweight for quick changing. The four piles were drilled in one day and also injected the same day. The advantage of this type of reinforcing the foundation was, that only little old concrete (1,50 m^3) had to be removed and little new concrete (about 4,50 m^3) had to be brought to the site, so it was possible to cut down costs. In comparison to a conventional foundation with heavy concrete blocs the old ones would have to be demolished and removed (12-15 m^3) and new foundation blocs would have to be cast (14-17 m^3) including all earth-work.

- Another example shows the new foundation of a skilift on the Pitztaler Gletscher in Tyrol. There, the glacier had shrinked extremely since the skilift had been erected, so the necessity of changing the position of the motor-station was urgent. A place located near the top of the mountain about 10 m beside the axis of the skilift proved as favorable foundation site, as ice was between 1,00 and 6,00 m thick. A system of twice 12 piles each was chosen for the station to build a new foundation. When calculating this foundation it was expected that the glacier might reduce another 1,00 – 5,00 meters and the foundation now is planned for the time when standing free. The site of the skilift was only accessible with helicopter and is situated at about 3500 m above sea-level. Maximum load for heli-transport was about 800 kg, so drilling equipment had to be lightweight. The whole foundation was realized in summer 1998 within three weeks.

- Also down in the valley the use of micro-piles can be a favorable foundation alternative, as proven by the following example. In Matrei in East-Tyrol a new coupling 8-seat gondola system had to be realized. The station down in the valley was situated on a 3,00 – 4,00 m soft landfill layer consisting of sand, silt and clay. In this case settlement was the problem, which had to be solved, as beside the station a fully automatic garage for the gondolas was erected and differenial settelment had to be avoided. As stones were expected obstacles rammed piles would not have been the right choice, so a foundation using micro-piles was proposed. 650 meter of piles with a length of up to seven meters were drilled within two weeks. The costs for the pile-foundation were less than for a shallow foundation, where landfill would have had to be removed and filled with concrete and the settlement problem would not have been solved.

- Another example, when the use of micro-piles makes it possible to realize the erection of a new ropeway system on the Patscherkofel in Innsbruck despite of environmental objections, is shown in the following.
  Due to severe restrictions of the Innsbruck water-support authorities and geolocical problems, the first project using conventional shallow foundations for the pillars was rejected with the explanation that huge excavations for the foundations would cause severe influences on the ground-water, beeing one of the drinking water resources of Innsbruck. With the proposal to use micro-piles as an alternative, the severe imposts of the authorities could be fulfilled, as it was possible to minimize the excavations with the use of micro-piles and to produce papers – a study by the University of Innsbruck -, which confirm the possibility to use micro-piles within restricted water support areas without danger for drinking water. The second objection was based on expected geological problems – sliding slopes, rock-fall – and could also be solved with the use of micro-piles and the possibility to shift pillars transverse to the ropeway axis, where the piles can take over the tieing forces due to excentricity. With the use of micro-piles also the exceptional loads due to avalanches and rock-fall will be posed on hard ground. This new system will be erected in summer 1999

Cost Comparison

For the investor and ropeway manager one point is very important – costs.
In the following two examples of pillar-foundations the costs of a shallow foundation are compared to the costs of a foundation with micro-piles for a new pillar-foundation as well as for the reinforcement of an old shallow foundation. Comparison is made for a foundation in gravel in a slope of about 35° inclination for a new ropeway system (1) and for the renewal of an old ropeway system (2). In both examles the is only accessible by a material ropeway. The use of helicopter-transport increases the costs for concrete depending on flight times up to US$ 250 / m³, but is not considered in the following comparison. Price in US$, paid in Austria in summer 1998. Total price is rounded to one $.

1. New pillar foundation - Shallow foundation

Pos	Specification	Amount	Unit price	Total price
1	Excavation	195 m³	6,10	1.190,--
2	Building pit lining	65 m²	58,34	3.792,--
3	Concrete	14 m³	438,64	6.141,--
4	Concrete formwork	20 m²	37,95	759,--
5	Reinforcement	600 kg	1,25	750,--
6	Backfilling	195 m²	3,80	741,--
	Total price shallow foundation 1			13.373,--
	Total price shallow foundation without lining 2			9.581,--

New pillar foundation – micro-pile foundation

Pos	Specification	Amount	Unit price	Total price
1	Excavation	21 m³	6,10	128,--
2	Micro-piles	24 m	304,58	7.310,--
3	Concrete	3 m³	438,64	1.316,--
4	Concrete formwork	5 m²	37,95	190,--
5	Reinforcement	240 kg	1,25	300,--
6	Backfilling	21 m²	3,80	80,--
	Total price micro-pile foundation			9.324,--
	Advantage price micro-pile foundation for one pillar 1			4.049,--
	Advantage price micro-pile foundation for one pillar 2			257,--

2. Demolision of old shallow foundation – new foundation

Pos	Specification	Amount	Unit price	Total price
1	Excavation	195 m³	6,10	1.190,--
2	Demolition concrete	12 m³	85,--	1.020,--
2	Building pit lining	65 m²	58,34	3.792,--
3	Concrete	14 m³	438,64	6.141,--
4	Concrete formwork	20 m²	37,95	759,--
5	Reinforcement	600 kg	1,25	750,--
6	Backfilling	195 m²	3,80	741,--
	Total price shallow foundation 1			14.393,--
	Total price shallow foundation without lining 2			10.601,--

Reinforcement old shallow foundation with micro-piles

Pos	Specification	Amount	Unit price	Total price
1	Excavation	10 m³	6,10	61,--
2	Part demolition concrete	1,51m³	85,--	128,--
3	Micro-piles	24 m	304,58	7.310,--
3	Concrete	3 m³	438,64	1.316,--
4	Concrete formwork	10 m²	37,95	380,--
5	Reinforcement	300 kg	1,25	375,--
6	Backfilling	10 m²	3,80	38,--
	Total price micro-pile foundation reinforcement			9.608,--
	Advantage micro-pile foundation 1			4.785,--
	Advantage micro-pile foundation without lining 2			993,--

In case of heli-transport the advantage for the use of a micro-pile foundation increases at about US$ 3500 per pillar.

Summary

Micro-piles as a foundation element in ropeway engineering cannot only be used to solve occuring technical foundation problems but also to provide a cost saving alternative to conventional shallow foundations executed till now in most cases. The use of micro-piles can also fulfill severe imposts by environmental impact analysis. So micro-piles can contribute a lot to future solutions of ropeway engineering in the third millenium.

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