Micropiles: Past; Present.....and Future

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ABSTRACT : Introduced and patented by the Author, in 1950's, afterwards diffused under the name of *Pali Radice* (translated as *Root Piles, Pieux Racines, Wurzelpfähle, Estaca Raiz ...*) Micropiles are now an essential feature of "Modern Foundations", as well as of "Reinforced Soil" . In time, different technologies were introduced, particularly focussed on Micropiles for high load bearing capacities. The main applications of Micropiles were and are : a) "Single Piles" in substitution of conventional piles, for normal Foundations; for such cases the most diffused are the *Steel Micropiles*, forced into the subground, no matter of the soil disturbance (Displacement Piles) b) "Groups" or "Networks" of Micropiles for several different problems of "Soil Reinforcement" and "Special Foundations". For such problems it is essential the use of Micropiles offering *full skin friction all along their shaft*, placed with *smooth technologies not disturbing the equilibrium of the soil*; *Pali Radice* or similar are appropriate (No Displacement Micropiles).

1. INTRODUCTION

Geotechnics is a special branch of Engineering, where a very close connection between Theory and Practice is essential. This basic requirement, clearly stressed by the great Terzaghi, is not always evident in the current large Geotechnical Literature. Formulae, Tables, Diagrams, Charts, Programs ... proposed in Conferences, Seminars, Symposia ... have an enormous attractive force on Geotechnical people, particularly young people, engaged in the solution of actual problems. Such documents, introduced by more or less reputable proponents, are a profitable and responsibility escaping short cut for the designer. Design so supported are, rightly or wrongly, generally accepted because in most cases, lacking a previous field confirmation, there is no way to demonstrate that they are erroneous.

"*In pure science a very sharp distinction is made between Hypotheses, Theory, and Laws. The difference between these three categories resides exclusively in the weight of Sustaining Evidence. On the other hand, in Foundation and Earthwork Engineering, everything is called a Theory after it appears in print, and if the theory finds its way into a textbook, many readers are inclined to consider it a Law*"(Terzaghi Presidential address – 1936 – First International Soil Mechanics Congress. Cambridge U.S.A.).

Notwithstanding this Solemn Warning a dichotomy between Theory and Practice is still affecting the development of Geotechnics, although, as a matter of fact, actual problems, when in the hands of the Field Operators, very frequently appear in a very different light from the proposed theoretical approach. Some modifications are required, sometimes under the push of urgence.

Experience, Reflection, and why not, Imagination are required, in the search of Solutions technically suitable, as well as economically convenient.

The Author, which spent all his professional life as a Practicioner, recalls, in this paper, some difficult real cases, in which he was engaged and which he successfully carried out through original solutions, suggested by Reflection more then by Theories. The aim of the present paper is, very modestly, to stimulate Reflection and Imagination in Geotechnics.
"*Imagination is better than Knowledge*" says Einstein.

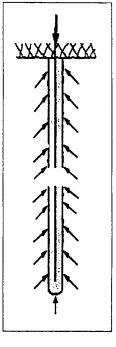
2. THE SOIL/PILE INTERACTION

Micropiles are cast-in-place piles. It is well known that the soil/pile interaction depends, primarily, on the mechanical characteristic of the soil; but it must be recalled, too, that it, depends, in a non negligible way, on the outer surface of the pile (skin) as well as on the installation procedures.

Consequently there are DISPLACEMENT MICRO PILES, forced into the soil or, on the other hand, NO DISPLACEMENT MICRO PILES, where the integrity of the natural soil is preserved to the best. *Pali Radice* belong to this second category, whereas *Steel Micropiles* belong to the first one.

3. THE PALO RADICE

(*Rootpile, Pieu Racine, Wurzelpfähle, Estaca raiz ...*).
First Micropile, originated in 1950's.



Main features:

- NO DISPLACEMENT pile, cast-in-place under limited pressure (in case, gravity pressure)
- Skin friction all along the shaft
- Sand/Cement mix.
- Steel bars (single or in cages) reinforcement.
- Performed with any inclination.
- *Singles* or arranged in *Groups* or *Networks* (*Reinforced Soil*)
- Simple, not costly, technologies
- Minimum Settlements
- No buckling

The *Palo Radice* was primarily used for:
STRENGTHENING WORKS, to be carried out on existing structures, such as:

- Underpinning
- Landslides prevention
- Excavations in urban areas
- Subways
- Tunnels
- Towers

In time it proved to be appropriate even for difficult *NEW FOUNDATIONS* in substitution of conventional piling.

3.1. UNDERPINNING WITH PALI RADICE

The pattern of a *Pali Radice* underpinning looks like the roots of a tree, sunk in the soil and extending, in the upper structure, as the fibres in the trunk. (Fig. 1)

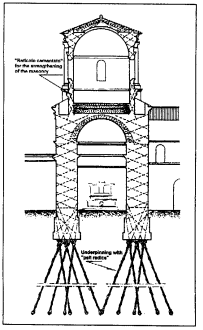


Fig. 1. Underpinning and reinforcement of a Monument in Rome

All the above was suggested by a basic *Reflection*: the structure *exists* and, although in critical conditions, it is, up to the last minute, *in equilibrium*.
The safety Factor of the existing foundation is probably very low, but, in any case, not less than the value of one.
Therefore the underpinning must not neglect or obliterate the existing foundation but it must be an *additional presidium* for the stability of the construction; even if dimensioned, for safety reasons, up to the full structure's load.
Minimum Settlement under load is essential.

3.2 LANDSLIDES PREVENTION

In an inclined slope the upper part of the soil has a tendency to slide down on the lower layers.
The classical structure for a landslide prevention has been, from old times, a Gravity Retaining Wall; provided such structure can be constructed; but, in several cases, this is not possible. Anyway looking at a Retaining Wall one can note that its main feature is the *Gravity* determined by its dimensions; the mechanical resistance of its material, as well as its structural continuity has not a great importance: the retaining wall may be obtained even with loose brittle stones or with gravely gabions.

Such consideration led to the idea of the *Reticolo di Pali Radice* (*Reticulated Root Piles*, in short *R.R.P.*) which was the first example of the *In Situ Soil Reinforcement* (fig. 2).

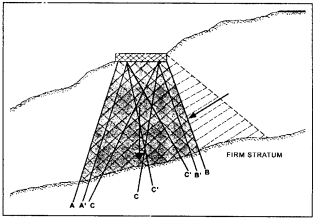


Fig. 2. Reticulated Root Piles for Gravity Retaining Walls

In a *R.R.P.* structure the main element is no more the complexity of the piles, but the *Soil*, which already *exists*, with its *Gravity*.
The axial load bearing capacity of the *piles* has no importance; what matters is their density in order to encompass the soil. Rock blocks and other obstacles, sometimes present in the sliding mass , are enclosed in the *R.R.P.* wall and become positive elements instead of negative factors.(fig.3)

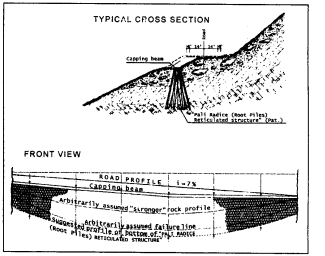


Fig. 3. Landslide prevention with *R.R.P.* in the U.S.A.

Water tables, if present, are not cut off, but can freely traverse the structure. All of this is possible provided the network is carried out by the classical *Pali Radice* offering *skin friction all along their shaft*, as well as a no displacement installation procedure. This is to be remembered.

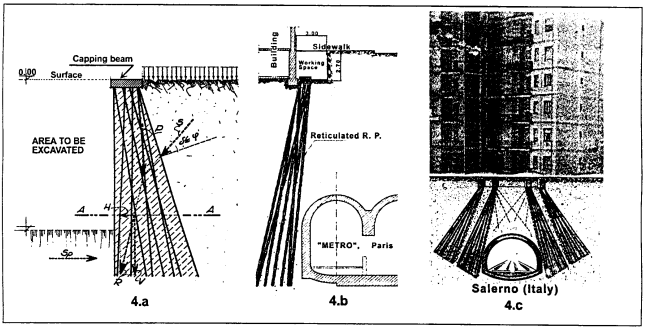


Fig. 4. Excavations in Urban areas (4.a) and Subways (4.b and 4.c)

3.3 EXCAVATIONS IN URBAN AREAS. SUBWAYS

The *R.R.P. Gravity Retaining Walls* have been successfully used to protect existing buildings during excavations in urban areas (fig. 4a) or during the construction of Subways (fig. 4b and 4c); the ductility of the system allowed for appropriate pattern for the Micropiles, according to the different specific problems to be solved.
Generally as for the generality of the *R.R.P. Gravity Walls*, the axial load bearing capacity of the *Pali Radice* has not a great importance except for the case c) where the network of Micropiles has the double purpose of Retaining Walls and of Underpinning of the full building; for the above the reinforcement of the *Pali Radice* was adequately increased.

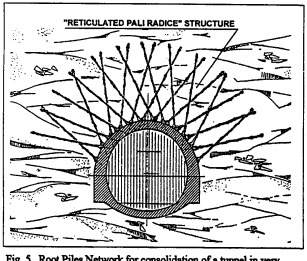


Fig. 5. Root Piles Network for consolidation of a tunnel in very loose soil

3.4. TUNNELS IN STATIC CRISIS

Some cases of consolidation of tunnels, excavated in very loose soils and consequently subject to unbalanced external pressure on the R.C. lining, were solved by a very original intervention based on a network of *Pali Radice*.
The above did not aim to a connection between the lining and some external competent soil layer, like in Rock Bolting, because such soil was not available. The purpose of the network, instead, was to achieve some sort of *Reinforced Soil outer Arch* for receiving and distributing the external pressure. The scheme was absolutely unusual but ... it worked and was successfully introduced in several other cases.

3.5 THE CASE OF THE LEANING TOWERS

Several Old Historical Leaning Towers, in the world, have been *Stabilized* by means of *Pali Radice*.
For instance:
In Fig. 6 the Burano Bell Tower in the Venice Lagoon; in fig. 7 a Minaret in the Middle East.
For such Monuments a normal Underpinning with *Pali Radice*, on account of its density, led to a *Reinforced Soil Block* "associated" to the upper structure, so realising a sole structure with a very low centre of gravity, sunk in the soil. The stability of such new structure is fully guaranteed.
It is noteworthy that in presence of this very efficient block of Reinforced Soil the load bearing capacity of the single piles looses its importance; no need, therefore of very long piles, in search of very competent strata.
In fig. 8 the above two Towers are compared, in the same scale, to the Pisa Tower; their static situation was much more critical.

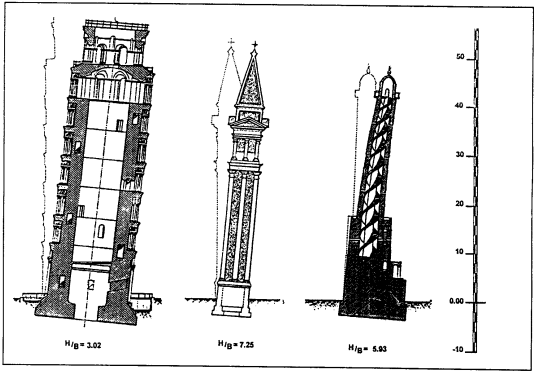


Fig. 8 The three Leaning Towers

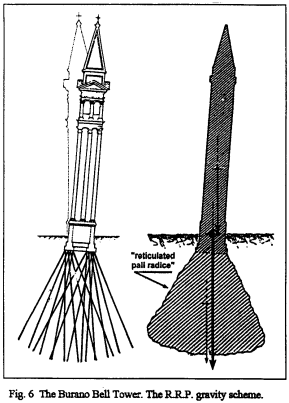


Fig. 6 The Burano Bell Tower. The R.R.P. gravity scheme.

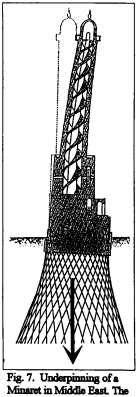


Fig. 7. Underpinning of a Minaret in Middle East. The *R.R.P.* gravity scheme.

3.5 THE CASE OF THE PISA LEANING TOWER

Due to the success obtained in several cases of stabilization of Historical Leaning Towers and supported by their sustaining references, a similar project was submitted about 25 years ago, to the International Competition, promoted by the Italian Government, for the *Stabilization of the Pisa Tower*. The project was signed by the Author and by Prof. Kerisel.

The Competition was not awarded; no decision was taken and, at the date of the present paper, the problem is still in the hands of a special Committee, appointed ten years ago.

As for the above project, based on a network of *Pali Radice*, the present Committee admits its full validity from the engineering point of view; but, its members solemnly declare that it cannot be accepted because the execution of the piles, although concealed in the low masonry and in the subsoil,... *spoils the Integrity of the Monument* ... Therefore, the Committee, is looking for a solution which can be carried out *without touching* the Monument...

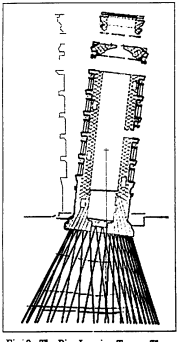


Fig. 9. The Pisa Leaning Tower. The *R.R.P.* underpinning proposed by KERISEL and LIZZI

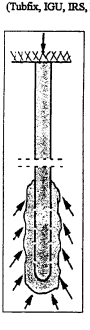
At this point it is noteworthy to remember that the problem to be solved is not any, small or large, *straightening* of the Tower but its definitive *Stabilization*; that is, its complete and ultimate standstill.

It is very important to remember, once again, that all the cases listed in this chapter 3 require: 1) *Full collaboration* between the soil and the piles 2) *Smoothly installation procedures* of the piles in the soil (no displacement piles). Such requirement are, up to date, offered by the classical old *Palo Radice*. On the other hand such micropile showed a peculiar high load bearing capacity, only limited by the crushing resistance of the cross section of the shaft.

Therefore the tendency arose to increase the steel reinforcement to obtain more resistant sections. Eventually, *Steel Micropiles* grouted in the subsoil were introduced and largely used for *New Foundations*, in substitution of conventional piles.

4. THE STEEL MICROPILES

(Tubfix, IGU, IRS, Pieu Aiguille ...)



Main features:

- DISPLACEMENT PILES
- Steel shaft, forced in the subsoil by high pressure grouting
- High load bearing capacity
- Skin friction concentrated in the lower part of the shaft

Compared to the *Palo Radice:*

- More elaborate workmanship
- More expensive
- Higher settlements (centimetres) due to the elastic shortening of the upper part of the steel shaft, heavily stressed.
- Risk of Buckling
- Risk of Corrosion

5. THE DEVELOPMENT OF MICROPILES FOR MODERN FOUNDATIONS

To date several types of micropiles are in use, offering different features ... different advantages ... different costs ...
They have demonstrated their suitability for different problems, such as:

- *SINGLE MICROPILES FOR NEW FOUNDATIONS*
- *GROUPS OF MICROPILES* } *REINFORCED SOIL AND NEW FOUNDATIONS*
- *NETWORK OF MICROPILES* }

5.1 *SINGLE MICROPILES FOR NEW FOUNDATIONS*

The possibility to entrust very high loads to small diameter piles has raised great interest all over the world.
The *Steel Micropiles* are preferred and largely in use. The design of such foundations is based, as for the old conventional piles, on the results of field Load Tests

$$Q = n \times p$$

where the total load is supported by n piles, engaged on their *working load* p.

5.2 *GROUPS OF MICROPILES*

It is well known , from the experience in the U.S.A. on Driven Piles (*Displacement Piles*) that with such piles constructed at close spacing, there is a decrease of the *Efficiency*, that is a decrease of the load bearing capacity of the single piles.
The same is to be expected with *Steel Micropiles* "forced" in the subsoil by high pressure, or by other systems aimed to an increase of the load bearing capacity of the single pile, to the expense of the integrity of the surrounding soil. Such micropiles must be considered *Displacement Piles*, like the Driven Piles.
A completely different picture can be expected with *Full Friction Micropiles*, smoothly introduced in the soil (*Pali Radice* or similar) as *No Displacement Piles*.
Several Full Scale checking and Model Tests, have demonstrated that, *for such micropiles*, a substantial increase in their total load bearing capacity is obtained when piles are constructed at a close spacing. (fig. 10)
A more marked positive effect is obtained when micropiles are arranged in a Network. (fig. 11)

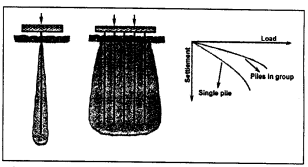


Fig. 10 Group of Full Friction Micropiles

.5.2.2 *NETWORK OF MICROPILES*

The most impressing application of *Full Friction No Displacement Micropiles* (*Pali Radice* or similar) is offered by piles arranged in Networks. (Fig. 11)

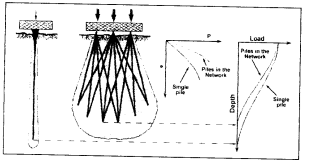


Fig. 11 Network of Root Piles for Foundations

In the previous Chapter n. 3, several *Pali Radice Networks* have been illustrated; for them, generally, the main element is the Soil whereas the piles have a secondary function. But the *Pali Radice Networks* demonstrated their suitability even for New Foundations, where the piles resume their position as the main bearing element.
One of the first typical cases is illustrated in fig. 12.
For the foundation of a very tall and heavy Viaduct in the Naples area the original design provided for Large Diameter Piles.
On the field, that was impossible on account of the presence of large boulders in the subsoil. In substitution a *Pali Radice Network* was carried out: diameter of the piles 25 cm., for a 40 tons working load bearing capacity each (as decided after some load tests on single piles).
The settlements of the full structure, accurately checked during its construction, did not correspond to the settlements which could be expected by the tests on single piles; practically there was no settlement at all, as a clear demonstration of a positive *Efficiency*, that is an advantage that could not be expected by *Steel Micropiles*.
Several other actual cases confirmed the above *Network Effect* offered by *Pali Radice Networks*.
In fig. 11 the possible explanation of the Network Effect is explained:

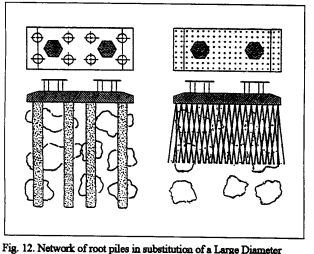


Fig. 12. Network of root piles in substitution of a Large Diameter Piles Foundation. Naples

- The threedimensional network of micropiles produces, in the block of soil, some sort of *Lateral Confinement* which increases the load bearing capacity of the single piles, so allowing a reduction on their length.
- Anyway, the total load of the construction is taken, as usual, on the top, solely by the piles, strengthened as above; it is improper to say that part of the load is taken by the soil.
- An adequate reinforcement of the top of the piles (for a few meters) is appropriate.
- Essential for the above *Network Effect* is the use of *Full Friction no Displacement Micropiles*.(*Pali Radice* or similar)

Noteworthy for the above scheme, is the essential active function of the piles, including the *Lateral Confinement* introduced by their network pattern; the function of the Soil is, in these cases, only passive, different from the cases illustrated in the Chapter 3 (Gravity Retaining Walls) where the function of the soil is pre-eminent.

6. THE DESIGN OF A GROUP OR A NETWORK OF MICROPILES

As usual in Geotechnics the design is carried out through different hypothesis, leading to a final Engineering Judgement.
In the Group or Network of Micropiles the first conservative hypothesis is the classical behaviour of any conventional pile foundation:

$$Q = n \times p$$

where the p is the *working load* of the single pile.
But the possibility of a *Group* or *Network Effect* can suggest an increase of p and consequently a possible *reduction in the number of piles* or a *reduction of their length*.
On the other hand the block Soil/Pile is sunk in the Soil as a unit; for which the load Q, applied on the top, is supported by the bottom resistance Q_b plus the side resistance S x s with S as the lateral surface and s as the unit skin resistance:

$$Q = Q_b + S \times s$$

7. THE FUTURE FOR MICROPILES

The future for Micropiles is moving in three directions:

a) SINGLE MICROPILES for Foundation in substitution of Conventional Piles.
Very important for such Foundations is the load bearing capacity of the piles. *Steel Micropiles* are the most appropriate and very much diffused.
Even classical Micropiles (*Pali Radice*) are used.
It is ironic to note that the original great diffusion of Large Diameter Piles has originated an increase in the diffusion of Micropiles. This is due to the several difficulties connected with the execution of Large Diameter Piles, compared to the more simple installation procedures of Micropiles and the possibility of not expensive Load Tests.

b) The REINFORCED SOIL, for several different problems, is nowadays gaining the greatest interest and perhaps is becoming a new branch of Geotechnics. The Soil is reinstated as the main support of the Man's Construction.
Full Friction No Displacement Micropiles are requested.

c) The NETWORK OF PALI RADICE (ROOT PILES) for heavy Foundations is gaining interest on account of the possibility of reducting of the costs.

Different exigencies push Industry for ever new typologies:
For the Single Piles, their load bearing capacity is essential, notwithstanding the disturbance in the soil.
For the Reinforced Soil, on the contrary, it is essential to introduce the least disturbance in the soil.
For the Network of *Pali Radice* (*Root Piles*), for Heavy Foundations, the Load Bearing Capacity of the Single Piles is important as well as a not great disturbance of the soil

S. GROUPS (OR NLTWORK) OF MICROPILES V/S PILED RAFTS

Groups (or Networks) of Micropiles belong to the same structural scheme as the Piled Rafts; because both of them draw their Load Bearing Capacity (in short L.B.C.) from a plurality of piles connected on their tops by a Reinforced Concrete cap (Raft).
From the combined L.B.C. of the piles associated to the L.B.C. of the overhanging Raft, two cases are possible (fig. 13):

A) PILES FOUNDATIONS with RAFT, where in the presence of a soil of convenient stiffness, the Raft is in *tight contact with the soil* and may offer a L.B.C. in the *limits of the settlement corresponding to the Working Load of the Piles*. The sum of the two loads, for any settlement, set up a Safety Load for the full structure.
Anyway it is very important , for the case A), to stress that if, for any reason, the contact Raft/Soil fails, the contribution of the Raft disappears and the Foundation must rely on the Piles only. Therefore the case A) is to be estimated as a PILE FOUNDATION with the conservative possible contribution of the Raft; a classification as a Piled Raft would be improper.

B) RAFT FOUNDATIONS with PILES. In soft soils, where *large settlements can be expected*, (and, overall, *can be accepted*), the Piles are in a "creep state" that is they may offer a constant Failure Load, no matter of the settlements.
At the beginning of the Loading, the raft, even in case of a very tight connection with the surface soil, *transmits the total load on the piles*, whereas the soil is not yet adequately stressed. After a few centimeters (or millimeters) the piles reach their Failure Load and from this moment they became only an obstacle to the further settlements of the raft; just like any other natural or artificial boulder to be found in the subground.
The only effect is *a reduction of the settlements*. As in the previous case A) the sum of the L.B.C. of the raft with the L.B.C. of the piles make up a Safety Load.
The number of piles may vary in very large limits, because they does not represent the foundation but only a limiting factor of the settlements.
In case of failing of the expected raft/soil contact the structure do not loose its functions, *provided a further settlement may be accepted*. In the figure this event is illustrated by a shifting from the Chart ② to the Chart ③.
The second case B) cannot be classified as a Pile Foundation because the leading behaviour is dictated by the raft; it is the peculiar RAFT FOUNDATION as reported in Literature.

In summary, for both the cases A) and B) above illustrated any pile complex is appropriate. What matters is their L.B.C. (increased, in case, by Group or Network effects, ..., influence of the Raft acting as a "capping beam" ...).

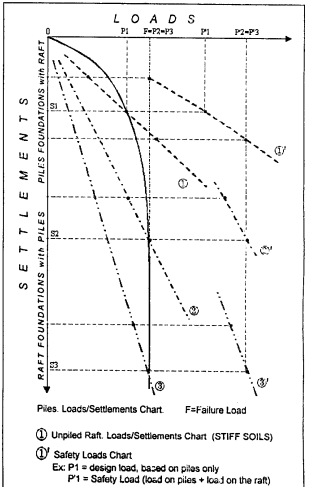


Fig. 13. PILES FOUNDATION with RAFT and RAFT FOUNDATIONS with PILES

For the case A), illustrated by the chart ① in the figure, the L.B.C. of piles *before the limit of Failure* is essential, leaving the contribution of the Raft on the Safety side.
For the case B) illustrated by the charts ② and ③ what is pertinent is the acceptable settlements, to be adequately reduced by the action of the piles.
In conclusion, for both the case A) and B) a Group or a Network of micropiles looks more appropriate and attractive than a structure based on spaced very long Large Diameter Piles; for several reasons:

- the Load Bearing Capacity of the single micropile is increased by the Group or Network effect
- the design of the Load/Settlement chart up to the Ultimate Load (Failure) for a Group or a Network of Micropiles may be better assessed through field tests (even as a "rough estimate") than in the case of Large Diameter Piles.

9. THE STANDARDS

Micropiles is a branch of Engineering, moving ahead.
Standards, Rules, Specification ... are very useful to protect the correct execution of what has been tested and approved. Anyway they represent the PAST.
On the other hand it is important to leave open door to Reflection, Imagination, always looking for new improvements, ... new results ... That is the FUTURE.

10. CONCLUSIONS

"Micropiles" is, nowadays a general term, comprising several different technologies for the solution of a large plurality of problems. Among them there are:

- *Displacement Micropiles*, where the main feature is the Load Bearing Capacity of the single elements, notwithstanding any possible soil disturbance, in substitution of conventional piles. Generally: *Steel Micropiles.*
- *No Displacement Micropiles*, whose essential feature is the *full frictional bond* with the surrounding soil, with a minimum disturbance for the subground. Arranged in *Groups* or in *Networks* they are the basis of *Reinforced Soil* for several applications such as *Landslide Prevention, Underpinning, Special Foundations Problems, Piled Rafts* ... Best suited: *Pali Radice* or similar.

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