Ground Anchors, soil nails and tension piles, what's the difference.

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1. Introduction.

Actually this is a lot of confusion about the meaning of the terms ground anchors, soil nails and tension piles or micropiles working in tension. This was mainly due to the fact that there is no clear definition and/or classification of ground anchors. So the difference between ground anchors, soil nails and tension piles is not always clear.

The existing European Standards for ground anchors, micropiles and soil nailing contain a lot of valuable information. However a lot of cases exist which are not covered by the existing execution standards and/or by Eurocode 7.

The fact that GEWI bars and self drilling rods are more and more used as reinforcement for ground anchors, soil nails and micropiles working in tension contributes to the actual confusion.

2. Eurocode 7:

Par. 8.1.1 Scope:

(2) This section is applicable to:
- *pre-stressed anchorages consisting of an anchor head, a tendon free length and a tendon bond length bonded to the ground by grout;*
- *non pre-stressed anchorages consisting of an anchor head, a tendon free length and a restraint such as a fixed anchor length bonded to the ground by grout, a deadman anchorage, a screw anchor or a rock bolt.*

(3) This section should not be applied to soil nails.

Comment:
In Eurocode 7 the term "anchorages" is used while in EN 1537 the term "ground anchors" is used.

Par. 8.5.2 Design values of pull-out resistance determined from the results of tests:

(1)P The design value of the pull-out resistance shall be derived from the characteristic value using the equation:

$$R_{a;d} = R_{a;k}/\gamma_a \qquad (8.2)$$

NOTE The partial factor, γ_a, takes into account unfavourable deviations of the pull-out resistance of the anchorage.

(2)P The partial factors γ_a defined in A.3.3.4(1)P shall be used in equation (8.2).

NOTE The value of the partial factor may be set by the National annex. The recommended values for persistent and transient situations are given in Table A.12.

(3) The characteristic value should be related to the suitability test results by applying a correlation factor ξ_a.

NOTE 8.5.2(3) refers to those types of anchorage that are not individually checked by acceptance tests. If a correlation factor ξ_a is used, it must be based on experience or provided for in the National annex.

Comment:
There is a clear gap between the anchorages considered in Eurocode 7 and EN 1537.

It is not clear why Eurocode 7 is also dealing with anchorages that are not individually checked by acceptance tests, while EN 1537 is only dealing with ground anchors that are checked individually by acceptance tests (= According to EN 1537 passive anchors can only be considered as ground anchors when every anchor is tested).

Par. 8.5.3 Design values of pull-out resistance determined by calculations:

(1) The design value of the pull-out resistance shall be assessed according to the principles in 2.4.7 and 2.4.8, where appropriate.

Comment:
The principle is clear, but there is no indication on the safety factors to be introduced.

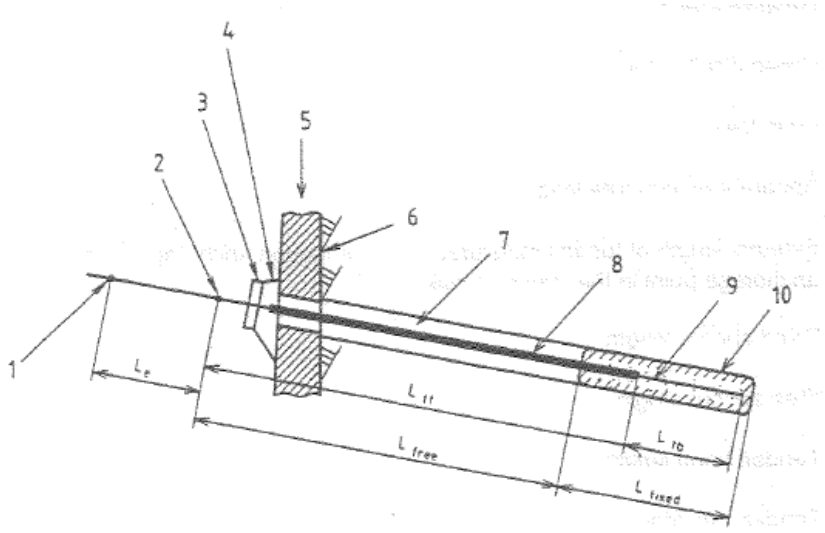
3. European Standards Execution of special geotechnical works:

2.1 EN 1537 – 1999 : ground anchors.

Chapter 1 : Scope

An anchor consists of an anchor head, a free anchor length and a fixed anchor length which is bonded to the ground by grout.

Chapter 3 : Terms, definitions and symbols:
Anchor : an installation capable of transmitting an applied tensile load to a load bearing stratum.



Key

1 Anchorage point at jack during stressing
2 Anchorage point at anchor head in service
3 Bearing plate
4 Lold transfer black
5 Structural element
6 Soll/rock
7 Borehole
8 Debonding sleeve
9 Tendon
10 Grout body

Figure 1: sketch of a ground anchor – details of anchor head and head protection omitted.

Chapter
9.7. acceptance test:
Each working anchor shall be subjected to an acceptance test. The objectives … .

Comment:
According to EN 1537 – 1999 a ground anchor has an anchor head, a free anchor length and a fixed anchor length and has to be subjected to an acceptance test.

2.2 EN 14199 – 2003 : Micropiles

Chapter 1: Scope

1.2. Micropiles are structural members to transfer actions to the ground and may contain bearing elements to transfer loads or to limit deformations. ….

Chapter 3: Terms and definitions
3.1. Micropile:
piles which have a small diameter (smaller than 300 mm outer diameter for bored piles and smaller than 150mm for displacement piles) and can be installed with small rigs.

Chapter 9: Micropile testing
9.3.2.3.3. unless otherwise specified for micropiles working in tension at least one static load test should be performed for the first 25 micropiles and 1 for each next 25 micropiles.

2.3 prEN 14490 : Soil nailing

Chapter 1: Scope
1.1 Soil nailing is a construction technique used to enhance / maintain the stability of a soil mass by installation of reinforcing elements (soil nails). Typical examples of soil nailing are given in Annex A.

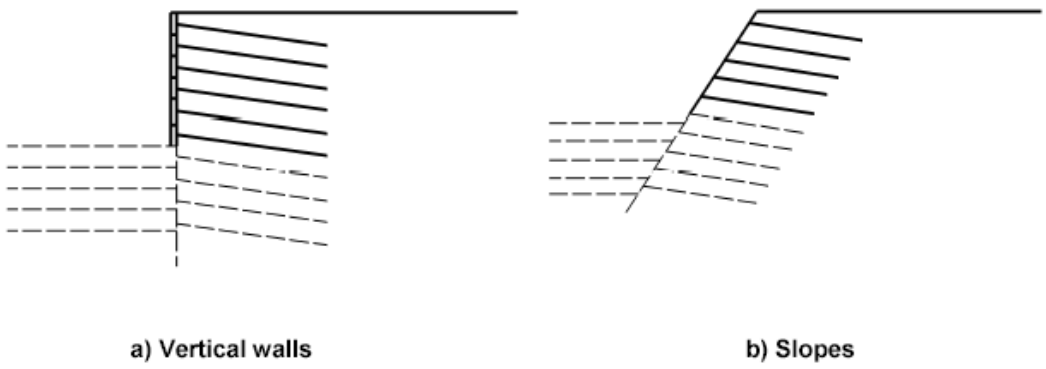


Figure A.1 — Typical stabilisation by soil nailing

Chapter 3: Terms and definitions
3.15. soil nail:
reinforcement element installed into the ground , usually at a sub-horizontal angle that mobilises resistance with the soil along its entire length.

Chapter 9: Supervision, testing and monitoring
9.3.2.1. The frequency and procedures for soil nail load testing should be based on a consideration of the consequence of failure, as defined in EN 1990 , EN 1997 and EN 1990.

9.3.2.2. Table 1 describes the principal types of soil nail load tests, their purpose, when they are required and actions to be taken in the event of an non-compliant test result. Annex A gives guidance on test procedures, acceptance criteria and the equipment to be used for soil nail load tests. Table 2 suggests the frequency of soil nail load tests based on the category of geotechnical structure.

Table 1 — Definition of soil nail load tests

	Type of Soil Nail Load Test		
	Design Investigation Test	**Suitability Test**	**Acceptance Test**
Purpose of test	to investigate ultimate soil nail to ground bond resistance for design	to verify the ultimate soil nail to ground bond resistance used in the design	to demonstrate satisfactory soil nail performance at the acceptance load
When tested	Pre-design (if specified)	Before or during production works	During or on completion of production works
Type of nail used	Sacrificial	Sacrificial	Sacrificial or production
Action taken in case of non compliant test result	Not applicable	Review soil nail installation method and/or consider alternative soil nail length and layout	Consult designer for action to be taken and approval to continue
Comments	Caution should be exercised in applying investigation test results if type of nail & method of test nail installation is not the same as for the production works It is not always possible to install test nails in body of proposed structure so results may not be representative	If necessary at each different soil layer	Caution should be exercised when testing production nails not to overstress the nail to grout bond or cause damage to corrosion protection When a structural facing is used the test nail should be debonded within the zone of influence of the facing

Table 2 — Suggested frequency of soil nail load tests based on density of nails and geotechnical structure category

Test type	**Suggested Minimum Frequency of Load Tests**			
	Design investigation	**Suitability**	**Acceptance**	
			Number of soil nails per m^2 of slope > 1 per 1,5 m^2	**Number of soil nails per m^2 of slope ≤ 1 per 1,5 m^2**
Category 1: negligible risk to property or life	Optional	Optional	Optional	
Category 2: no abnormal risk to property or life	Optional	If no comparable experience of soil type: a minimum of 3 test nails with at least 1 test nail per soil type. Where direct experience exists then suitability tests are optional	For slope area: ≤ 1000 m^2 then 5 tests: > 1000 m^2 then 1 test per 400 m^2 Above criteria subject to a minimum of 1 test per soil type and excavation stage	For number of nails: ≤ 200 – 3 tests > 200 then test 1,5 % Above criteria subject to a minimum of 1 test per soil type and excavation stage
Category 3: all other structures not in category 1 or 2	Optional	A minimum of 6 test nails with at least 2 test nails per soil type.	For slope area: ≤ 1000 m^2 then 5 tests >1000 m^2 then 1 test per 200 m^2 Above criteria subject to a minimum of 1 test per soil type and excavation stage	For number of nails: ≤ 200 - 5 tests > 200 - test 2,5 % of nails Above criteria subject to a minimum of 1 test per soil type and excavation stage

NOTE 1 Geotechnical category of structure as defined in EN1997.

NOTE 2 Test nails should be evenly distributed throughout the structure.

NOTE 3 The frequency of testing is a suggested minimum.

NOTE 4 Where Suitability Tests are carried out the number of Acceptance Tests can be reduced on a pro-rata basis.

4. Actual situation:

When looking to the actual situation a clear difference should be made between:

- ground anchors with tendon elements of high strength steel
- ground anchors with tendon elements of low strength steel
- soil nails
- tension piles

4.1 Ground anchors with tendon elements of high strength steel:

When tendon elements of high strength steel are used (= mostly strands) it is clear that prestressing is always necessary to limit the deformation of the anchors. As in this case the additional work for the testing of the anchors is very small testing of all the anchors is common practice.

For the design of these anchors the safety factors given in Table A.12 of Eurocode 7 have to be applied. However it should be clear that the values of Table A.12 can oly be used if the testing procedure of EN 1537 is strictly followed. This means that for each jobsite preliminary suitability tests have to be performed on sacrificial anchors. This is only common practice for big jobsites.

For small jobsites the pull-out resistance of the anchors is determined by calculations and is checked by means of 2 or 3 suitability tests on sacrificial anchors who are installed together with the working anchors or on working anchors. In this case an R factor comparable to the R factors given in Tables A6, A7 and A8 of Eurocode 7 for shaft in tension should be introduced. As the anchors are individually checked by acceptance tests a correlation factor must not be applied.

4.2 Ground anchors with tendon elements of low strength steel:

For the ground anchors with tendon elements of low strength steel a clear difference has to be made between:

- prestressed ground anchors
- passive anchors that are individually checked by acceptance tests
- passive anchors that are not individually checked by acceptance tests

4.2.1 Prestressed ground anchors:

As for ground anchors with tendon elements of high strength steel the additional work for the testing of the anchors is very small. So it may be assumed that testing of every anchor is common practice.

The same design methods can be applied as for ground anchors with tendon elements of high strength steel can be applied.

4.2.2 Passive anchors that are individually checked by acceptance tests:

Also in this case the additional work for the testing of the anchors is very small. So it may be assumed that testing of every anchor is common practice.

The same design methods can be applied as for ground anchors with tendon elements of high strength steel can be applied.

4.2.3 Passive anchors that are not individually checked by acceptance tests:

This type of anchor is not considered in EN 1537.

According to Eurocode 7 the characteristic value should be related to the suitability test results by applying a correlation factor ξ_a.

It is proposed to apply for this type of anchor the same safety factors as for tension piles.

4.3 Soil nails:

The execution methods of soil nails and micropiles working in tension are almost the same. So the difference beween soil nails and micropiles working in tension is mostly related to the design method and the assumed load distribution in the reinforcement element.

When soil nails are used specific methods have to be used for to calculate the maximum load in the reinforcement element, the length of the reinforcement element and the reinforcement of the facing.

Load tests on soil nails can only be performed on sacrificial nails and on working nails which are debonded within the zone of influence of the facing. So when soil nails are used the number of tests to be performed and

the necessary provisions have to be given in the specifications.

Due to the completely different design approach for soil nailing direct comparison of soil nails and ground anchors or tension piles is not possible.

4.4 Tension piles:

Although the use of tension piles is very common for big infrastructure works, f.i. MV piles with capacities of up to 300kN for quay walls, their use is not generally accepted for the horizontal support of retaining structures. This is probably due to the fact that there are no clear rules for the design and testing of tension piles.

When tension piles are used for the horizontal support of retaining walls, there will be no load transfer from the pile to the ground within earth pressure failure zone, cfr figure 3. Within the earth pressure failure zone the relative displacement between the pile and the surrounding soil is always very small. So only the length of the pile behind the earth pressure failure zone can be considered.

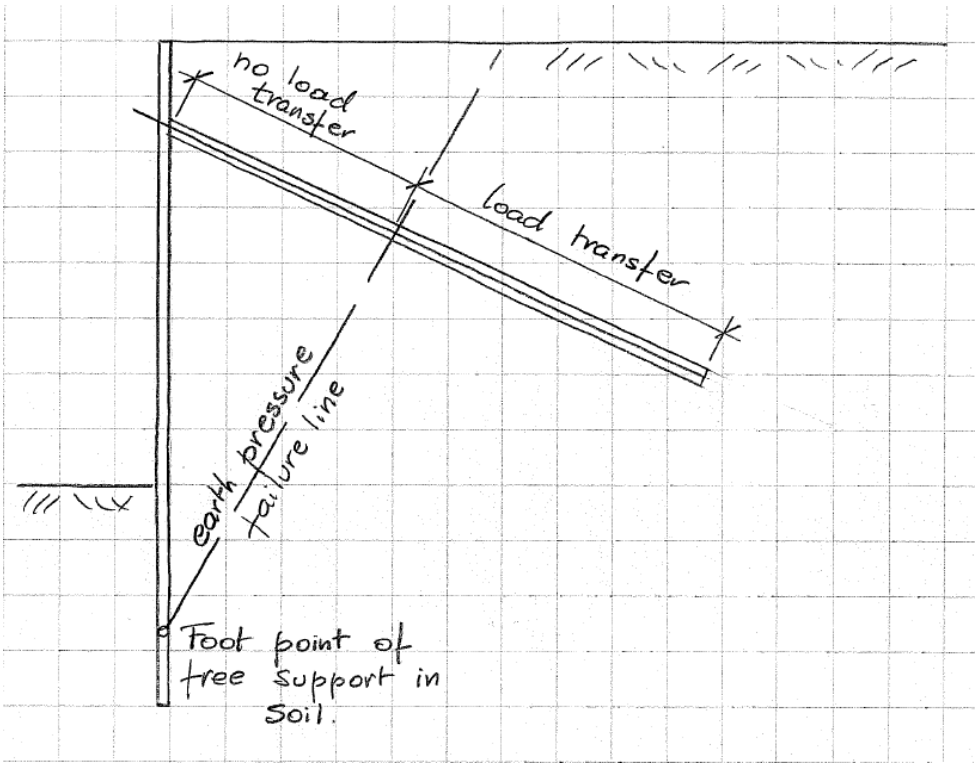


Figure 3

For the determination of the displacement of the reaining structure it has to be assumed that no load transfer is

taking place over the pile length within the earth pressure failure zone.

The methods normally used to determine the pull-out resistance of ground anchors can also be used for tension piles when the same installation methods are applied. However it should be clear that the same safety factors cannot be used because tension piles are not individually checked by acceptance tests. So at least an R factor comparable to the R factors given in Tables A6, A7 and A8 of Eurocode 7 for shaft in tension should be introduced and a correlation factor as given in Table A9 of Eurocode 7 to take into account the number of tests performed.

It is also clear that the overall stability has to be checked in a similar way as for pre-stressed ground anchors, cfr. figure 4.

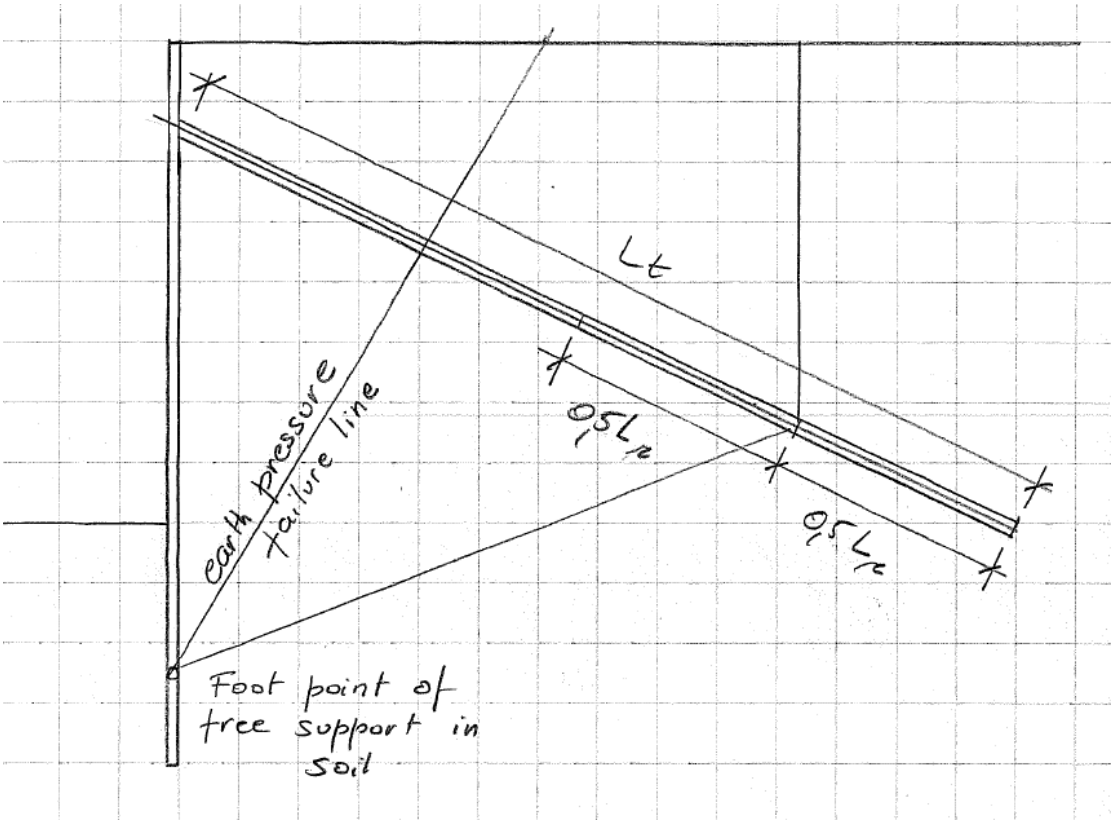


Figure 4

When load tests are performed on tension piles installed for the horizontal support of retaining structures, the piles have to be debonded over the length of the earth pressure failure zone. When the length of the piles has to be increased to obtain enough safety for the overall stability the debonded length has to be increased to $L_t - L_r$, with:
L_t = the total length of the tension pile

L_r = the minimum length necessary to transfer the load to the soil

5. Proposal:

5.1 Classification:

In order to cover all types of ground anchors which are actually installed the following classification is proposed:

- prestressed ground anchors;
- passive ground anchors;
- tension (micro)piles;
- soil nails.

a) Prestressed ground anchors :

- prestressed ground anchors may have a tendon element of high strength or low strength steel.
- they always have a free length and a fixed length;
- the fixed length is installed behind the so called active wedge and in this way that the necessary factor of safety is available for the overall stability;
- they are always tested. When testing is not possible due to an excessive deformation of the retaining wall or the reaction system a higher value of the safety factor has to be introduced.
- they are always prestressed by means of a hydraulic jack.

b) Passive ground anchors:

- passive ground anchors always have a tendon element of low strength steel;
- they always have a free length and a fixed length; the fixed length is installed behind the so called active wedge and in this way that the necessary factor of safety is available for the overall stability;
- the number of tests to be performed has to be clearly specified in the tender documents and/or in the method statement;
- it has to be demonstrated that the displacement of the anchor head is smaller than the allowable displacement of the retaining structure.

c) Tension Piles:

- tension (micro)piles may have a tendon element of high strength or of low strength steel;
- they have only a fixed length;

the length of the piles is determined in this way that the necessary factor of safety is available for the overall stability,
- the number of tests to be performed has to be clearly specified in the tender documents and/or method statement. Tests on working piles can only be performed for vertical piles. For inclined piles a free length of min. 2 meters has to be provided (= especially installed piles);
- it has to be demonstrated that the displacement of the pile head is smaller than the allowable displacement of the retaining structure.

d) Soil nails:
- soil nails have always a tendon element of low strength steel;
- they have only a fixed length;
- soil nails are used as soil reinforcement and not as anchors.

5.2 Design:

The ultimate skin friction over the fixed length is determined taking into account the applied drilling and injection technique.

The factors of safety to be introduced are determined based on the type and number of executed tests:
- preliminary tests
- tests on sacrificial anchors
- acceptance tests on working anchors.

5.3 Control tests.

Following types of tests can be considered.

a) Prestressed ground anchors:
- preliminary tests on sacrificial anchors
- suitability tests on sacrificial anchors
- suitability tests on working anchors (= not foreseen in EC7 but should be allowed for temporary anchors)
- acceptance tests on all working anchors.

b) Passive ground anchors:
- preliminary tests on sacrificial anchors
- suitability tests on sacrificial anchors
- suitability tests on working anchors (= not foreseen in EC7 but should be allowed for temporary anchors)

- acceptance tests on working anchors.

c) Tension piles:
- preliminary tests on sacrificial piles
- suitability tests on sacrificial piles or on selected working piles (provided with a free length for inclined piles)

d) Soil nails:
- preliminary tests on sacrificial nails
- suitability tests on sacrificial nails.

6. Conclusions:

The information given in the available European Standards is not precise enough to allow a correct design of all the types of anchors that are actually installed.

In order to obtain a better agreement with the actual daily practice it is necessary to extend EN 1537 with passive ground anchors and to define in Eurocode 7 the safety factors which have to be taken in to account when acceptance tests are not performed on all working anchors. Further on it is proposed to elaborate a technical document dealing with the use of tension (micro)piles as anchoring elements.