**ABSTRACT:**

The three parts of the report deal with the problem of removable anchor systems and survey the systems currently offered on the market. A new development of the company DYWIDAG-Systems International (DSI) is a removable strand anchor. By inductive heating of the strands at the top end of the grout body before inserting, a breaking point is created. After their life span, the strands can be cut by excessive pressure and recovered.

Electrically insulated strand anchors according to Eurocode EN 1537 offer the possibility of a quality control for anchors already inserted but in practice they have been hardly used so far in Austria and Germany. The construction differences to traditional anchor systems are shown and the problems of negative measuring results are dealt with. So far owners have tended to refuse payment if the measurements point at an electric connection of the tendon and/or the anchor head to the soil. If electric controls and the resulting quality improvement should prevail, new and graded criteria must be created for the acceptance and payment.

Because of their cost advantages, self-drilling anchors and nails are in practice used for temporary purposes. Currently there are frequently given permanent functions too. The possibilities of producing controlled corrosion protection for the tendons are limited. The use of these systems for permanent purposes therefore requires a careful examination of geotechnical conditions, thorough training of the drilling personnel and the control of the insertion by experts familiar with the problems.

**PREFACE:**

Many details of anchor technology have remained unchanged since their introduction into geotechnics, while others have changed continually. Much has been invented, tried and yet not taken over on a large scale into general construction practice. Thus the following details are not entirely new, either, but they are increasingly important in practice, which is due to changing construction tasks and also to the developments towards a united Europe.
1) Removable anchor systems

With the success of the strand anchors also for the use at relatively low anchor loads, the problem of removability soon arose. While monobar anchors with rolled threads can be easily recovered (at least theoretically) in the free steel length, and while with compression pipe anchors the tendon is also removable in the grouted length (not, however, the compression pipe itself), the removal of strand anchors requires a nearly total destruction of the grout body. If the removal of the strands in the free length is sufficient, the tendon must be cut at the top end of the grout body. Both the destruction of the grout body and the cutting of the tendon in the soil may prove difficult in practice.

1.1) Staggered anchors

Staggered anchors have also been successfully used for temporary purposes in Germany and Austria, e.g. by DYWIDAG-Systems International. The regulations of DIN 4125 do not specifically deal with the design, execution and control of such anchors. The standard formally only deals with anchors which provide one grouted length in one drilling hole. At the time of the last update of the standard, the standard committee had obviously not yet considered the possibility to install several grouted lengths successfully in one hole.

Staggered anchors with two or more grout bodies do, however, not contradict DIN 4125. As to the required distance between grout bodies, the standard says in paragraph 7.6.5:

**7.6.5 Installation of the grout bodies:**
The minimum distance between the grout bodies at working loads of up to 700 kN must be 1.0 m and at working loads of 1300 kN it must be 1.5 m (interpolation is allowed in between). If necessary, grout bodies must be fanned or staggered or anchor group tests must be carried out according to paragraph 10.6.

The axis distance of the grout bodies of a staggered anchor as presented here is not defined, because the grout bodies do not lie next to each other. It is obvious, however, that DIN 4125 in the current version does not entirely apply to the staggered anchors, even if all construction parts are controlled and certified.

DIN 4125 chapter 1 says about such anchors or anchor components:

**1. Field of applications**
Remark: For those construction types or construction elements of temporary anchors which cannot be judged according to this standard, proof of the suitability for the application purpose must be made according to the construction supervisory regulations, e.g. by a general supervisory admission.
Thus a general supervisory admission is only one example for the proof of suitability, although it may be the rule. According to the (German) construction regulations, the suitability can be proved by a general supervisory admission or by accordance with the commonly valid technical construction regulations (e.g. standards) or by an agreement in individual cases. So far, a general supervisory admission for staggered anchors has not been applied for in Germany. The cost advantages do not seem to be substantial enough to justify the effort (and costs) of a formal admission procedure. The control practice of such anchors shows that the cost for those is clearly higher than for anchors whose strands are of equal length. The length of the grout bodies cannot be extended beyond a certain limit when the anchors should secure e.g. deep construction excavations. At a certain point, the static safety becomes problematic as with very large grout body lengths the assumption that the forces are centered in the middle of the grout body length is somewhat arbitrary. And yet staggered anchors are an economically interesting alternative to other anchors under certain circumstances.

1.2 Systems with strand recovery in the free length

The company DYWIDAG-Systems International GmbH. (DSI) has developed a method to tear off the individual strands of an anchor after their life span at the top end of the grout body. Before the assembly of the anchor, the strands are equipped with a planned breaking point there (used strand: 0.62”, grade 1670/1860). These breaking points are inductively heated to a temperature of 600°C. Thus the prestressing steel is changed so in its structure that the ultimate load of the individual strand decreases from 279 kN to 220 kN. The working load of the strand is thus reduced to 126 kN. This weakening before the installation can be exactly reproduced and it always works.

Trials in the past to weaken or cut the strands (e.g. by burning it off with thermite) on the installed anchor after its life span have not always been satisfactory. Finally, the weakening or cutting mechanism must survive the life span of the anchor undamaged after having already been exposed to the strains of installation, grouting and stressing.

After their life span, the strands are individually torn off at the breaking point and drawn out of the drilling hole. As only the friction between the strands and the inner side of the sheathing pipes has to be overcome, only little force is necessary for the pulling, provided the strands were installed parallel and untwisted. In the past, the removable DYWIDAG anchors were partly produced as staggered anchors as well. Figure 1.2.-1 shows the force-extension diagram of a 0.5” strand weakened at different temperatures and the decrease of the ultimate stress.
Figure 1.2.-1: force-extension diagram of a 0.5” strand weakened at different temperatures and the decrease of the ultimate stress.

Outlook

The use of removable anchors will probably increase in the future. Preference will be given to systems which guarantee removal and are not dependent on factors which can be insufficiently influenced and controlled (as e.g. grout body geometry). Removable anchors will not only be of interest where the property owners may raise unreasonable claims. In densely-built areas and difficult construction terrains, e.g. the saturated sands of Berlin, non-removable anchors may lead to construction difficulties and additional costs. All in all, the development of completely removable anchors is not finished yet. As long as the removability mainly or exclusively depends on sufficiently weakening the grout bodies, so that the strands largely lose their connection to the cement stone, their application under extreme circumstances remains a risk. Apart from the cost factor “particularly careful installation”, the pull-out procedure is expensive also with destroyed bond in the grouted length. At the time of removal, there is rarely enough space in front of the anchor head to pull out the tendons e.g. with a caterpillar. It might be rewarding to think about an improvement of the removal technology.

2) Electrically insulated strand anchors according to EN 1537

The unimpaired condition of the corrosion protection of built-in permanent anchors may be checked by measuring electric resistance when the anchors including the anchor heads are completely electrically separated from the ground by plastic pipes and insulation plates. Electric checks have been introduced in Switzerland for more than 10 years (Grimm 1995). Various companies and a corrosion commission have worked out “Recommendations for
Planning and Implementing Corrosion Protection of Permanent Soil and Rock Anchors” (Vollenweider 1989). These recommendations do not only contain the electrical checks, but they also make suggestions for the construction of anchors (which in Germany are part of the admission). Meanwhile, these recommendations have become obligatory in Switzerland. In Austria and Germany, the Swiss model is regularly presented at expert meetings. So far, however, these presentations have failed to create enthusiasm for electric-check anchors in these two countries.

The electric check (see figure 2-1) is normally carried out in two steps. The first step checks at the injected, but yet stressed anchor if the plastic sheathing of the steel tendon is undamaged. To that effect, a voltage (500 V, continuous current) is laid between the anchor head and the ground; the resistance between anchor head and ground should be higher than 0.1 Megaohm. A second measurement checks if the anchor head is electrically separated from the reinforcement of the anchored building. The check is carried out at the stressed anchor before the injection of the anchor head.

For reliable measuring, all parts of the anchor head must be clean and dry; the contact points themselves must be metallically bare. As the resistance of the anchor is increased by the resistance of the grounding element (e.g. steel bar) and of the cables and contacts, the latter must be kept as small as possible. The Swiss recommendations permit exceeding of the measuring values at 10% of the built-in anchors at the utmost, as long as the “faulty” anchors are statistically distributed. However, anchors whose electric resistance to the surrounding ground is lower than permitted by the recommendations are not deemed to be of no use there. But the unimpaired condition of their corrosion protection is not proven.

The company DYWIDAG-Systems International GmbH (DSI) offers an electric check anchor (described by Klöckner in 1995). It has been improved meanwhile and its installation and check do not pose any problem for a trained drilling crew.

It has already been mentioned that the check of the corrosion protection by measuring electric resistance has not yet prevailed in Germany and Austria, although it would be a suitable instrument to improve quality control for permanent anchors. The reason are not the slightly higher costs for production or the costs for the check itself. So far, it has not been determined how to proceed if the check shows a higher conductivity than might be expected with intact insulation. Customers as well as suppliers are interested in getting respectively producing technically perfect and corrosion-proof permanent anchors. The execution of electric checks could contribute to that because passing such a check requires careful work during production, transport and installation of the anchor. Particularly Germany tends to regard electric checks not as an instrument with which generally an increase in quality of the permanent anchor might be achieved. There are fears that certain owners (and also well-known special foundation engineering companies, which like to pass on anchoring to less experienced firms) might use the possibility of an electric check as an instrument to blame an anchoring firm in case of negative check results for inferior work quality and withhold parts of the agreed price.
This way of thinking must change! Of course, not every permanent anchor must be electrically checked. But for especially important or later on no more accessible anchors the electric check to prove the intactness of the corrosion protection could become a means to secure quality in Austria and Germany, too.

Permanent anchors have been state of the art technology for about 30 years and they have their fixed place among the instruments of special foundation engineering procedures (Wichter and Meininger 2000). Without permanent anchors, many exceptional construction projects all over the world have become far more expensive. Let’s not forget, however, that in European conceptions thirty years are only about a third of the life span which is expected from engineering constructions. So far, built-in permanent anchors could be checked to a limited extent only. Except for a control of parts of the anchor head and of the anchor capacity, if the preconditions for that were created at installation, there is no checking possibility. Corrosion of the steel tendon itself can not be seen before it has become obvious.
Most permanent anchors will probably be forgotten by their owners soon after their installation. The Brandenburg technical University currently carries out a research project for the German Institute for Construction Technology, in which the condition of anchors is systematically examined which were installed 20 and more years ago. The results of this study will hopefully increase the willingness to secure quality at the latest technical level when installing permanent anchors. The costs of this quality improvement, however, mustn’t be charged to the construction company, since it is mainly the owner who benefits from the improved product quality.

3) Self-drilling anchors, nails and piles

3.1) Temporary applications

DYWIDAG-Systems International offers anchors and accessories (drill bits, couplers, injection adapters and -pumps) for self-drilling anchors under the product name of DSI Hollow Core Anchors Type MAI, whose data are shown in table 3.1

The list of various systems of self-drilling anchors is not complete. Their basic principles are very similar. The material of the anchors are solid steel pipes with exterior rolled threads. With one-way drill-bits specially adapted to the specific soil conditions the anchors are inserted into the ground. The flushing is effected through the pipe. The spill is evacuated through the space between the drilling rod and the wall of the borehole. The flushing should be done with cement grout which should finally establish the bond between anchor and soil and take over the corrosion protection.

Table (3.1) Essential data of self-drilling system DSI Hollow Core Anchor Type MAI

<table>
<thead>
<tr>
<th>description</th>
<th>weight (kg/m)</th>
<th>exterior diameter (mm)</th>
<th>cross section (mm²)</th>
<th>yield load (kN)</th>
<th>ultimate load (kN)</th>
<th>working load (kN) ((\eta = 1.75))</th>
</tr>
</thead>
<tbody>
<tr>
<td>R25N</td>
<td>2.6</td>
<td>25</td>
<td>300</td>
<td>150</td>
<td>200</td>
<td>86</td>
</tr>
<tr>
<td>R32N</td>
<td>3.6</td>
<td>32</td>
<td>430</td>
<td>230</td>
<td>280</td>
<td>131</td>
</tr>
<tr>
<td>R32S</td>
<td>4.2</td>
<td>32</td>
<td>500</td>
<td>280</td>
<td>360</td>
<td>160</td>
</tr>
<tr>
<td>R38N</td>
<td>6.0</td>
<td>38</td>
<td>750</td>
<td>400</td>
<td>500</td>
<td>229</td>
</tr>
<tr>
<td>R51L</td>
<td>7.5</td>
<td>51</td>
<td>900</td>
<td>450</td>
<td>500</td>
<td>257</td>
</tr>
<tr>
<td>R51N</td>
<td>8.4</td>
<td>51</td>
<td>1050</td>
<td>630</td>
<td>800</td>
<td>360</td>
</tr>
<tr>
<td>T76N</td>
<td>15.0</td>
<td>76</td>
<td>1695</td>
<td>1200</td>
<td>1600</td>
<td>686</td>
</tr>
<tr>
<td>T76S</td>
<td>19.7</td>
<td>76</td>
<td>2327</td>
<td>1500</td>
<td>1900</td>
<td>857</td>
</tr>
</tbody>
</table>

In mining, self-drilling systems have been used for a long time as also in tunnelling. In Germany, the double-layer construction method is commonly used in traffic tunnels; after the installation of the inner layer, the outer layer with shotcrete and anchors loose their technical function and therefore the question of permanent corrosion protection is not relevant.

The use of anchors, nails and piles whose static elements consist of the drilling rods themselves, offers cost advantages compared to systems in which the drilling and the tendon installation are carried out in two steps.

The production of these construction elements without the necessity of casings in loose soils makes self-drilling systems for the production of anchors and bolts for temporary purposes an
interesting alternative to anchors according to DIN 4125, soil nails according to the regulations of the German Institute for Construction Technology (DiBt) or grouted piles with little diameter according to DIN 4128. The requirements concerning corrosion protection of temporary anchors and nails are less stringent compared to those for permanent anchors and nails. According to DIN 4128 (paragraph 9.2), however, the suitability must always be proved for piles with bond, i.e. the use of piles with self-drilling systems is dependent on either an agreement in the individual case or a general construction supervisory admission. This also applies for their use as anchors or soil nails for temporary purposes since self-drilling tendons are not mentioned in DIN 4125.

For temporary measures, the working load is particularly important, which can normally be proved by in situ load tests. There is hardly any difference between soil nails made of steel pipes and nails with steel tendons made of construction steels BSt 500 S or other admitted steels. As a rule, 3 % of all built-in nails must be checked. The aim of the checks must always be to prove the ultimate friction on which the calculation is based.

For ground anchors according to DIN 4125, not only the soil-mechanical working capacity of the grout body must be proved, also that the length of the grout body is limited respectively that there actually is the designed free anchor length. The free anchor length must be proved because the anchor force should be directed into the ground at a point with sufficient distance from the anchor head (or the anchored construction element). Therefore a grout body of defined length must be produced. Between the grout body and the anchor head, the soil is held together by prestressing of the anchor and thus prevented from distorting. The proof of the static safety in the so-called deep slip joint requires that the point of the main insertion of forces does not lie anywhere between anchor head and the bottom end of the anchor. If it is too close to the anchored construction, this proof cannot be made, and the static safety and the low deformation of the soil between the designed grout body and the anchored construction are not guaranteed.

The production of a defined pre-determined free anchor length with self-drilling anchors is not always granted in practice. Whenever the adherence to the pre-determined free anchor length is important for the low deformation of the anchored construction, it should be proved by tests that it can be realised also by self-drilling anchors in the given specific soil conditions.

3.2) Permanent applications

If self-drilling systems should be used as an alternative to traditional permanent anchors, soil nails and piles, they must (in Germany) be measured with regard to corrosion protection and the point of force insertion by the supervisory requirements which are applicable to these purposes (DIN 4125, admissions of the DiBt, DIN 4128). For anchors and nails this means that the tendons of self-drilling systems must have double corrosion protection on their entire length. This double corrosion protection consists, according to the present state of technology, of e.g. a homogenous and sufficiently thick cement coating of the tendon (first protective layer). Around this cement layer, a protective pipe of polymere (polyvinylchloride, polyethylene of high density) forms a second protective layer.

Owing to the production procedure, such a double protection for self-drilling systems cannot be guaranteed. If, on the one hand, one considers the possibility of an electric check of the
intactness of the corrosion protection for permanent anchors as desirable, it would be hard to agree that, on the other hand, one accepts that as early as during the installation of the anchor the strains of the anchor shaft must damage any corrosion protection to a hardly predictable extent.

For grout piles according to DIN 4128, conditions are slightly different and also the required safety factors are different from those for anchors and nails. The currently valid version of DIN 4128 was published in April 1983. Meanwhile several self-drilling anchor and pile systems have been developed and experiences have been gained during their use (at first mainly for temporary measures). On the basis of these experiences it can be proved that grout piles with small diameters as piles with bond with a centrally located tendon can also be produced with self-drilling procedures if certain by-conditions are considered.

The advertising brochures of some suppliers of self-drilling systems frequently point out that they meet the requirements of DIN 4128. A critical comparison shows that they don’t do so in every respect (table 3).

As self-drilling systems do not meet the requirements of DIN 4128 in every respect, their use in the field regulated by the construction supervisory board in Germany requires a proof of their suitability. As a rule, this proof can be obtained by a general supervisory admission by the German Institute for Construction Technology. In order to obtain this admission, the applicant must demonstrate (normally by producing in situ test piles and by subsequent excavation) that he himself or the companies supplied by him are able, under the given soil-mechanical conditions, to produce piles with the pre-determined inclination and length safely in a way that the corrosion protection meets at least the requirements of the table 1 in DIN 4128 and that the grout body diameters figuring in the calculation are achieved.

If a producer of tendons is given an admission, the piles must be produced under his responsible supervision by the construction companies in the way required by the admission (as it is also required from producers of permanent anchors for the distribution of their products).

In practice there is the danger that, if the staff of drilling companies is not sufficiently trained or the construction supervision is not sufficient, piles may be produced with self-drilling systems which are technically not equal to the requirements of DIN 4128. Of course, this danger exists with other systems, too. Owing to the special production procedure, the application of self-drilling systems for the production of grout piles which meet the quality standard of DIN 4128 requires a certain additional effort on the part of the construction supervision.

<table>
<thead>
<tr>
<th>Requirements according to DIN 4128</th>
<th>The self-drilling system</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Characteristic of the tendon and required corrosion protection</strong></td>
<td><strong>The tendons should meet DIN 1050 or consist of other steels admitted by the construction supervisory board – this must be proved by test certificates. Owing to the production procedure, the sufficient and homogeneous concrete/cement cover cannot be generally guaranteed. It must be proved by excavation of trial piles for each soil condition and the desired pile geometry.</strong></td>
</tr>
</tbody>
</table>
| By using tendons of steel, the cross section can be of solid steel, pipes or profiles acc. to DIN 1050. Also other steel types with admission by the construction supervisory board can be used with a maximum yield stress of 500 N/mm². For the entire length the tendons have to be corrosion protected. For the concrete/cement cover see table 1. | }
Production of cavity
For the entire length a stable cavity of defined geometrical cross section has to be produced. A cavity declined more than 15° to the vertical are only allowed to be produced with very stiff drilling rods or casings. The casings must be cleaned of spill and soil particles.

With self-drilling systems, the geometry of the cavity cannot be pre-determined, since it is dependent on the soil. The claim for sufficiently stiff drilling rods cannot be fulfilled with self-drilling systems. Cleaning impossible within the system.

Grouting
7.2 Grouting
Concrete or cement has to be used. During installation of the shaft a grouting pressure of minimum 5 bars has to be achieved in the load bearing section.

Achieving a controlled grouting pressure is impossible with self-drilling systems.

Regrouting
7.3 Regrouting
Regrouting is always necessary, if the hollow space is not grouted acc. to section 7.2, paragraph 1.

Regrouting is difficult with this system.

Table 3 Requirements according to DIN 4128 and the realization with self-drilling systems

In case of great lengths and low inclination of the boreholes (particularly with the larger steel diameters) in loose soils there is always the danger of the tendons touching the wall of the borehole on their bottom side and there having too little covering. Trials have shown, however, that small diameter piles with self-drilling tendons can be produced in such a way that the required corrosion protection is guaranteed. Like in any procedure in the field of special foundation engineering, this requires expert knowledge and care.

3.3 References

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