Development of expanding cement grouts for piles and grout anchors

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1 Subject

In 1993 Messrs. AZBUT (Anneliese Zementwerke AG in Germany) started in collabor-ation with the foundation industry, the development of a new expanding cement grout for geotechnical applications. Cement grouts are of common use for grout anchors, micropiles, MV-piles, or post-grouting of bored or driven piles. The grout generally is:

- Either pumped under low or medium pressure during the fabrication of the anchor or the pile (Primary Global Grouting)
- Either post-grouted at medium to high pressure in one or several stages, generally using TAM (Tubes à Manchettes) (Secondary Repeated and Selective grouting).
- Or by combination of both.

The traditional grouts (mostly water-cement mixtures or mortars) present a number of inconveniences or limitations, such as:

- The primary grouting, and even more the secondary selective grouting, is very much time consuming
- The secondary grouting with TAM, in order to guarantee for success, requires additional personnel, high workmanship of the operator, adequate planning and a close monitoring of the grouting process (pressures, flow and consumption)
- The pressurising period remains short; in case of low permeability soils, the degree of consolidation of the soil surrounding the anchor during the pressurising is very small and so is also the beneficial effect of the post-grouting (unless the grout is able to fill up the fissures, if any, in the soil);
- The hardening rate of the grouts is rather low, so that prestressing of the anchors or loading of the piles can be performed at earliest after 5 to 7 days; very often, this delay retards also the global construction planning (e.g. waiting time before starting deeper excavation).
- Some particular clays and shales are sensitive and may loose their shear characteristics if in contact with water (e.g. with rotary drilling); as a consequence, the anchor capacity drops to very low values.

The development of purpose made expanding cement grouts aimed to scatter for these limitations, and to achieve in a simple, controlled, uniform and economical way an excellent anchor capacity equivalent to post-grouted elements. Both approaches are schematically presented in Figure 1.

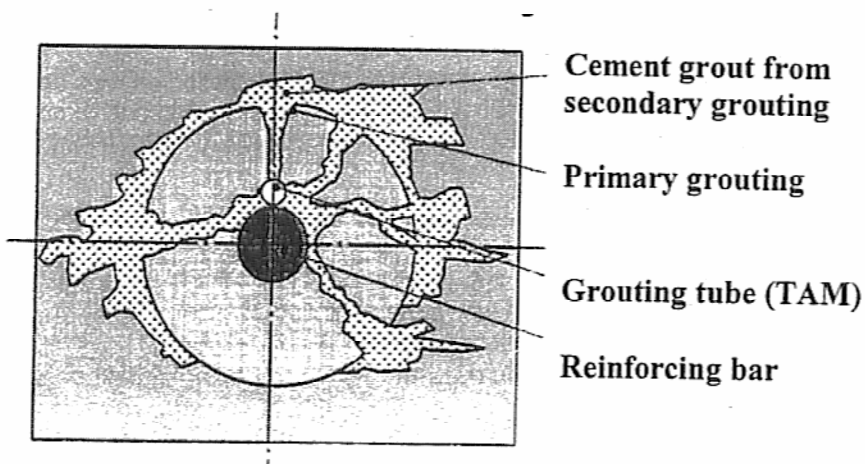

Figure 1a Anchoring with primary and secondary grouting

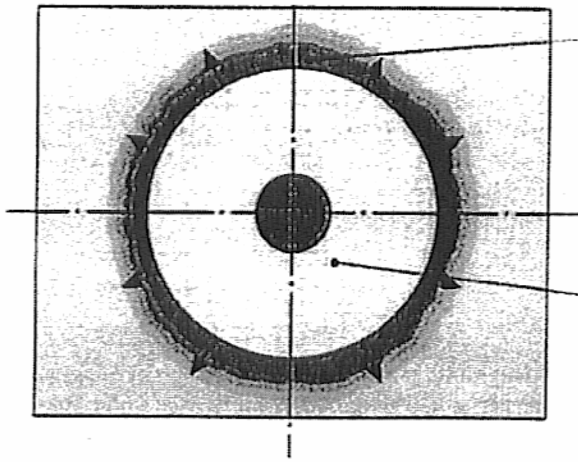

Figure 1b Anchoring with expanding grout

2 Expanding cements and mortars

2.1 Generalities

The volume-expansion of cement-bounded products can be achieved by 2 means:

- Through gas-forming
- Through the building of ettringite-crystals ($3CaO.Al_2O_3.3CaSO_4.32H_2O$).

When high strength and a remarkable increase in friction bond between the mortar and the surrounding soil is required, which is the case for most geotechnical applications in anchors and piles, one should focus on the second method.

In general terms one can state that expansion volume depends on the content of aluminate and sulphate in a specially configured mix with additives.

The use of expanding cements as such, is not new. Applications so far were a.o.:

- The prestressing of prefabricated concrete elements or shell structures
- The splitting of rocks in quarries
- The grouting of anchor boxes, anchor bolts, ...

Research on the feasibility of expanding cements to increase the shaft friction on piles and ground anchors started some 25 years ago in Canada (Sheikh, 1974). Results of load test on bored piles, fabricated with expanding concrete, were reported by Sheikh e.a. (1984, 1986) for bored piles in clay, and by Hassan e.a. (1993) for bored piles in shale.

In both cases, different mixes proportions of normal Portland cement, HAC (High Alumina Cement), molding plaster and quick lime was used. The volumetric expansion was low (2 to 3 % only), and developed very slowly (over about 1.000 hours or 6 weeks (see Figure 2). Nevertheless, a clear increase friction compared to a pile in traditional concrete, has been observed (Figure 3):

- For the test case 1 (piles in clay) : increase of q_s of about 53 – 55 %
- For the test case 2 (piles in shale) : increase of q_s from 60 kPa up to 100-110 kPa.

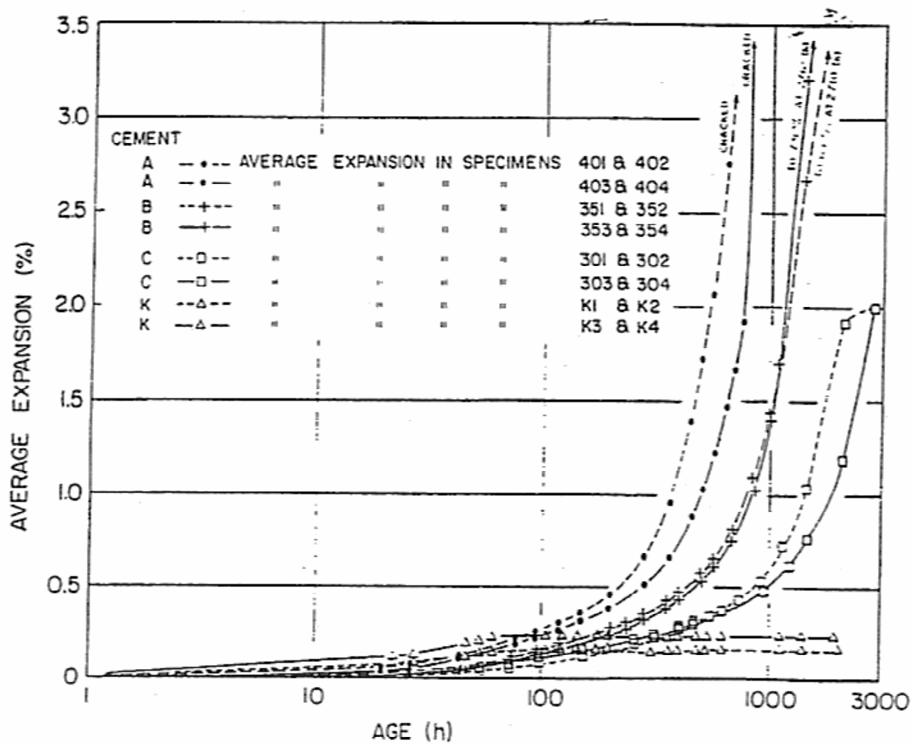

Figure 2 Average expansion vs. log of time for various cement mix proportions (Sheikh, 1985)

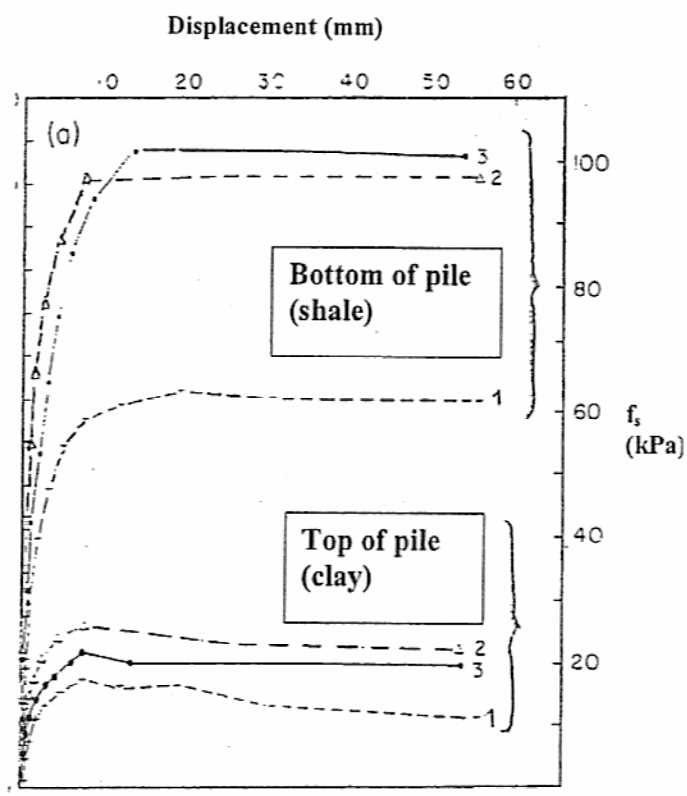

Figure 3 Skin friction transfer curves for clay and shale, with normal cement (1) and expanding cement-mix (2 and 3).

2.2 Basic criteria for the new expanding cement

At the beginning of the research program, the following criteria were put forward:

- The expansion of the basic product(s) should be adjustable in advance within small variations
- The volumetric free expansion should go from about 5% up to 20%; the expansion pressure should be able to go up to values of 5 to 10 bar (500 to 1.000 kPa) at minimum
- The expansion should occur in an early stage, prior to the setting of the grout
- The grout should be easy to fabricate on site and be easy to pump during the stage of installation; on the other hand, the viscosity should sufficiently increase with time to avoid that the expansion should preferentially extend in the longitudinal direction along the pile or the anchor and not in radial direction.
- The compressive strength (after 28 days) should be of at least 30 N/mm² and should develop fast, so that the pile or anchor can be loaded or prestressed after short time (< 7 days)
- Further on, the grout should have acceptable characteristics with regard to e.g. long term stability, resistivity to aggressive ground or groundwater, prevention of chemical attack of the reinforcing steel, ductility, ...

3 Characteristics of CIMEX

After 2,5 years of intensive laboratory testing by AZBUT, 2 new products were ready for initial field testing and commercialisation : the CIMEX5 and the CIMEX15. In this chapter the most relevant physical and mechanical characteristics are briefly described and commented.

3.1 Expansion volume

The development of the free expansion as a function of time has been measured on prismatic grout samples. The results are shown in Figure 4. One notices that both curves are qualitatively similar and so independent from the % of expanding additive in the product mix. As with common cement grouts, a small contraction occurs in the beginning of the hydration. After some hours, this shrinking is compensated by the expansion of the grout. Depending of the product mix, this expansion continuously increases, reaching its end value after say 1 day. Independent from the expander content, the expansion is completed after 24 to 30h.

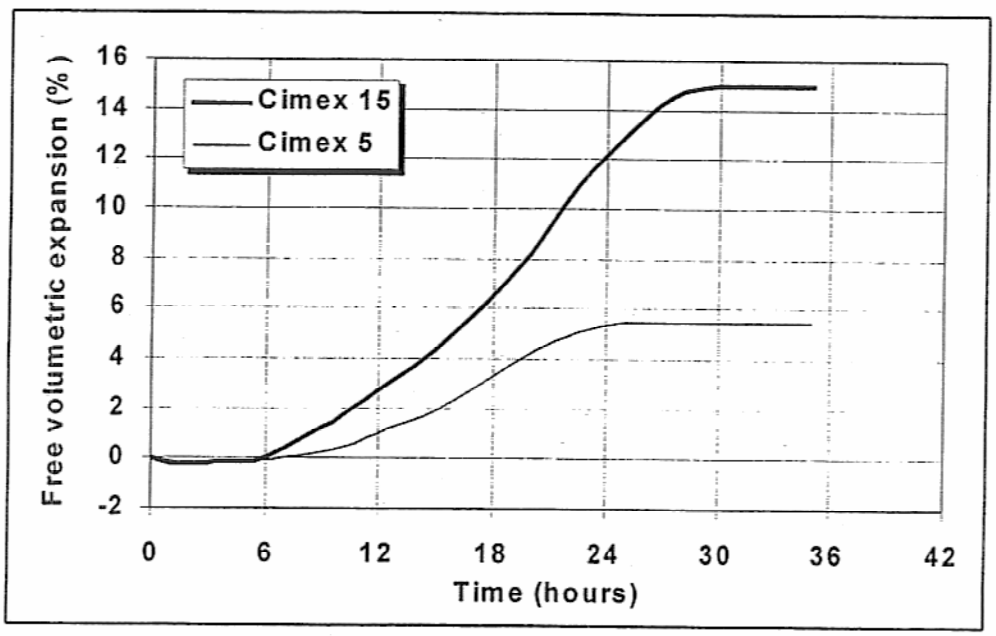

Figure 4 Evolution of free volumetric expansion vs. time

In complementary tests an additional water supply to the grout sample was allowed during the expansion. This was achieved by installing a fresh grout column in a saturated sand volume (see Figure 5). It appeared that the free expansion raised in these test to much higher values (30% on an average for the CIMEX15).

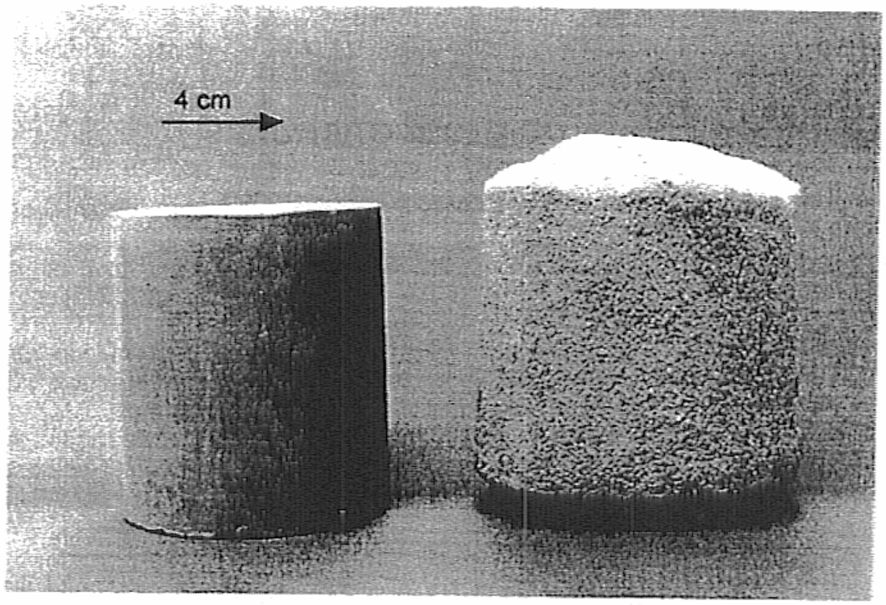

Figure 5 Traditional cement grout (left) and CIMEX15 after 30 hours hydration under free expansion in contact with saturated sand

3.2 Compressive strength

Short time after the expansion, the strength is build up rapidly. Compressive tests on prismatic samples have been executed for water-cement ratios varying between 0.32 and 0.36. With the W/C factor of 0.36, at 7 days, compressive strengths of 45 N/mm² for the CIMEX5 and of 32 N/mm² for the CIMEX15 were obtained (see Figure 6). During the hardening phase, no further expanding occurred, even not for samples that remained in contact with water.

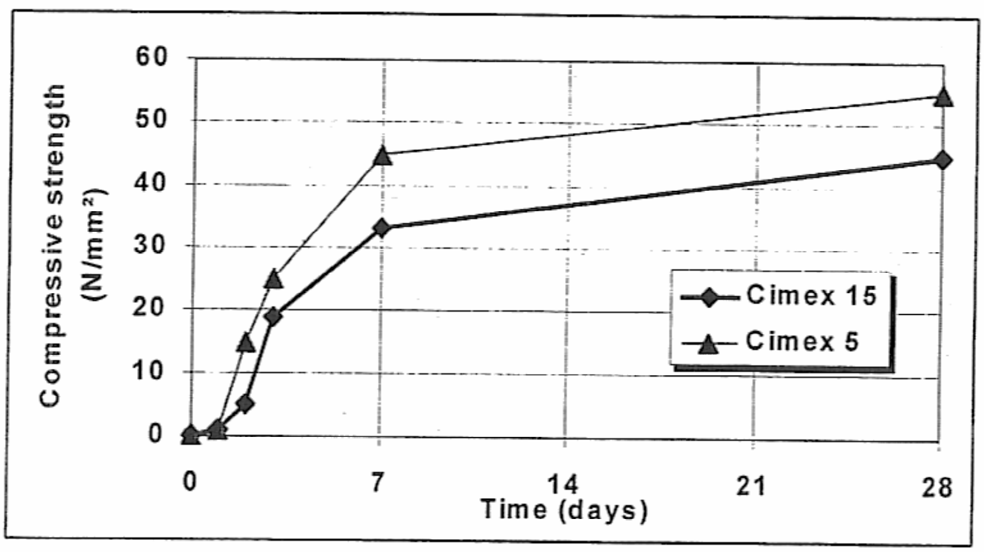

Figure 6 Evolution of compressive strength vs. time

3.3 Expansion pressure

In case the expansion is hindered (which is the case in the soil, where passive earth pressures are build up during the expansion of the cylindrical grout column) expansion pressures are build up as a result of the ettringit forming. Laboratory tests indicated that within a 2 days period, pressures of 500 kPa and more were build up at constant volume.

4 Initial in-situ tests on grout-anchors

The very first comparative in-situ tests have been executed on a plot of land in the West of Belgium. The results of the tests are detailed hereunder.

4.1 Subsoil information

In view of an extended research program on screw piles of the Atlas type, performed in 1992 (see De Cock e.a., 1993), a detailed soil investigation had been executed on the considered site, comprising cone penetration tests (CPT) with mechanical and electrical cones, flat dilatometer tests (DMT) and laboratory tests on soil samples. Figure 7 shows the results of a representative CPT, as well as the PMT limit pressures p_l as calculated from $q_c/2.5$, on one hand, and as deduced from the PMT using the relation $p_l = (p_1 + p_0)/2$, on the other hand.

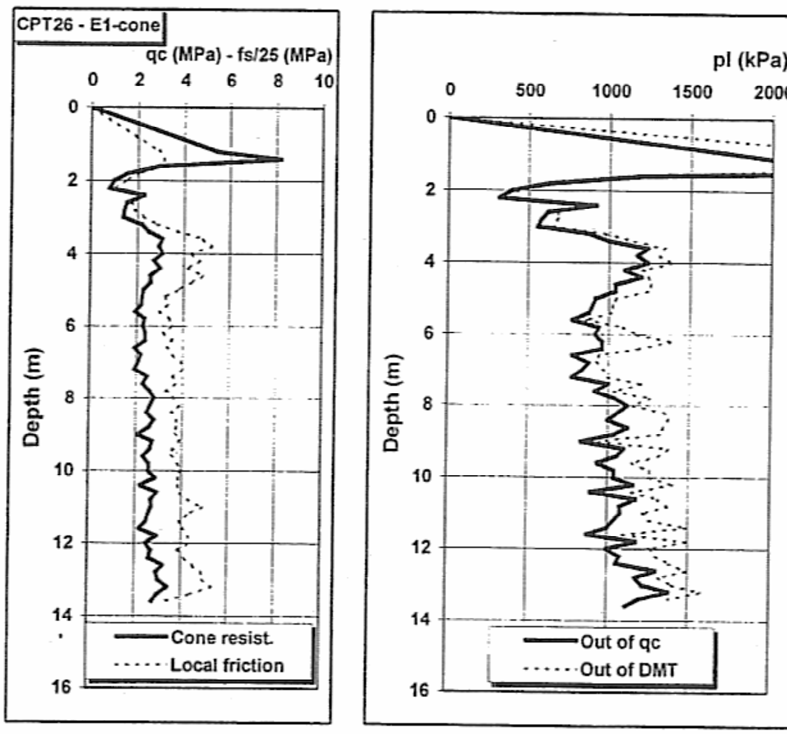

Figure 7 Relevant soil data from test site in Koekelare/Belgium

The subsoil consists of:

- somewhat heterogeneous top layers up to 5 m depth, consisting of sandy silt and clay up to clayey sand
- at larger depth : medium stiff to stiff somewhat sandy clay (tertiairy overconsoli-dated clay – Iepresian Clay).

The clay, in which the anchoring has been realised, is characterised by:

- cone resistances (electrical cone) in the order of 2.000 to 3.000 kPa; average between 5 and 13 m depth of 2.500 kPa
- local friction out of CPT : 60 to 100 kPa; average between 5 and 13 m depth of 95 kPa
- average limit pressure p_l deduced from CPT : 1.000 kPa
- average limit pressure p_l deduced from DMT : 1.200 kPa

4.2 Type of grout anchors installed

In a whole, 6 test anchors have been installed:

- 3 anchors of the "MONO" type, comprising a Dywidag bar ∅ 32 mm
- 3 anchors of the "DUPLEX" type, where the anchor body consists of an outer anchor tube ∅ 60 mm and an inner Dywidag bar ∅ 32 mm, connected at the deeper end of the anchor tube.

For each of both anchor types, 3 different of cement-grouts have been used:

- (as a reference) a normal cement CEM I 52.5 R (P50) and a W/C value of 0.5
- A CIMEX5 grout with a W/C of 0.36
- A CIMEX15 grout with a W/C of 0.36.

All anchors have a free length of 5.0 m and a bonding length of 8.0 m. All anchor holes have been drilled in the same way, using rotary drilling with tubes ∅ 133 mm and a tungsten bit ∅145 mm.

The reference anchors were grouted under pressure during the extraction of the drilling tubes. For the CIMEX anchors, the grout was added gravitary within any excess pressure during the tube extraction.

4.3 Load test results

Somewhat 3 weeks after installation, a static tensile loading test was performed on all 6 anchors. The load tests were performed according the test-method 3, as described in the preliminary version of the European grout anchor code prEN1537. The load is increased stepwise; each load step is maintained during at least 30' or 60'.

The load-displacement curves for the various anchors are collected in Figures 8 and 9.

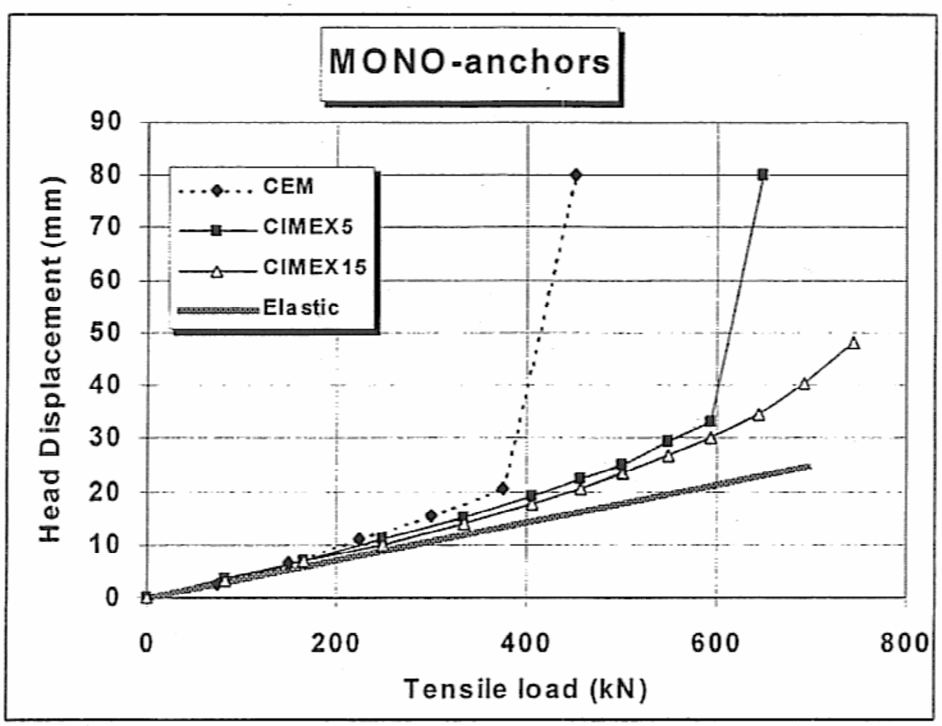

Figure 8 Results of tensile load tests on MONO-anchors

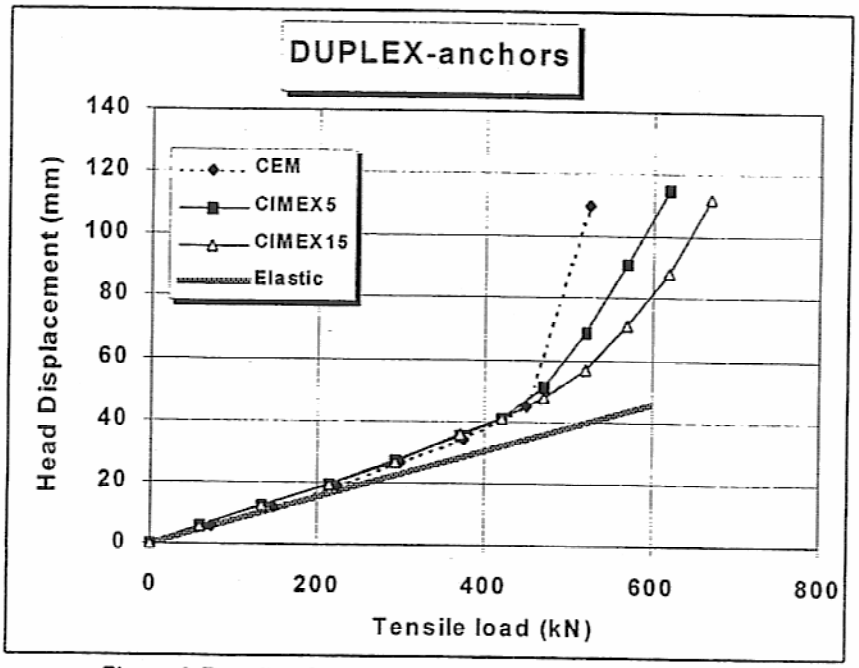

Figure 9 Results of tensile load tests on DUPLEX-anchors

With regard to the load tests and in particular with regard to the anchor behavior at the end of testing, the attention is drawn on the following:

- For the reference anchor "MONO-CEMENT": already at about 375 kN, an increased creep behaviour was observed; the anchor failed at about 425 kN
- For the "MONO-CIMEX5" anchor : stable behaviour at 595 kN, and initially also at 645 kN; however after 50' loading, the anchor suddenly failed
- For the "MONO-CIMEX15" anchor : stable behavior without any pronounced creep until end of the test, that means 745 kN; as the theoretical limit of elasticity of the steel was exceeded, the test was stopped
- For the reference anchor "DUPLEX-CEMENT" : light increase of the creep factor at 450 kN; the anchor failed at 525 kN
- For the "DUPLEX-CIMEX5" anchor: stable behaviour until 570 kN; the test was stopped at 620 kN for reasons of instability of the reaction frame
- For the "DUPLEX-CIMEX15" anchor: stable behavior until 620 kN, also during 20' at 670 kN; then sudden failure of the Dywidag bar.

4.4 Comparison and analysis of the load test results

Next table gives an overview of the failure loads deduced from the different load tests. The table also mentions the theoretical failure load, calculated on basis of the soil parameters given before and using the calculation method suggested by Bustamante e.a. in case of global pressure grouting and repetitive and selective pressure grouting respectively.

Considered case	Ultimate resistance for	
	MONO anchor	DUPLEX anchor
Theoretically according to Bustamante: ♦ Global grouting ♦ Selective grouting	 437 kN 787 kN	 437 kN 787 kN
From load tests: ♦ Normal cement ♦ CIMEX5 ♦ CIMEX 15	 425 kN 645 kN >> 745 kN	 525 kN > 620 kN >> 670 kN

From the results, one may deduce the following:

- The anchoring capacity of the reference anchors corresponds fairly well with the predictions according Bustamante, with some light underprediction for the DUPLEX anchor
- The use of expanding cement-compositions generally increases the anchor capacity in a very pronounced way. Further on, a somewhat stiffer and stronger behaviour is observed with the most expanding CIMEX15.
- The anchor capacity obtained with the CIMEX15 tends to achieve the theoretical values when using a repetitive and selective post-grouting.

All in all, these first tests showed the beneficial influence of the use of cement-grouts with large expanding capabilities. They tend to indicate that the initial goal – developing a grout which by its expanding and strength capabilities – could compete with a very much cost and time consuming post grouting, might be achieved. Further tests and experiences however will have to demonstrate the validity of this equivalency in other ground conditions.

5 Further applications

After the successful initial test results, further comparative tests have been executed in Belgium, as well as in France, Luxembourg and Germany, handling so also different cohesive soil types (marls and clays). All tests confirmed:

- the excellent resistance of the CIMEX anchors, comparable to post-grouted anchors
- the rapid hardening, allowing the anchors to be prestressed after 3 to 5 days
- the simplicity of the "ready-made" composed product, which can be mixed with the conventional grout-mixing units and its good pumpability.

During the last 2 years the cimex products were applied on many building sites in Germany (Bauer e.a., 1997), especially in cohesive soils were the desired anchor capacity with traditional methods is questioned or not achieved , or in cases where the time consumption for post-grouting operations is troubling the planning.

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