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The revised execution standard EN 12716 for jet grouting – amendments and changes explained

Le standard d'exécution EN 12716 par jet grouting révisée – suppléments et modifications expliquées

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ABSTRACT: In the course of 2018, CEN TC288, the European standard committee for geotechnical execution standards, has published a revised version of EN 12716, the execution standard for jet grouting. This revision replaces the previous version from 2001, which after 17 years of use was overdue for an overhaul in light of the huge technological progress made in jet grouting in design, execution as well as quality control and the vast amount of experience collected in this long period.
The main changes and amendments compared to the previous version have been developed and discussed by a team of 16 experts from 12 European nations. These experts did not only implement the current state of the art for jet grouting and added missing content, but also managed to condense the text considerably. New Annexes have been developed, mainly about how the strength of the jet grouting material should be determined as well as which tests have to be conducted and records to be taken to achieve a good product quality.
This resulted in more stringent requirements for quality control including digital real time recording of all execution parameters as well as depth dependent frequencies of verticality measurements. The authors were convenor and technical editor of the working group of experts within CEN TC 288 that produced this revision of the standard and will explain the amendments and changes to the standard.

RÉSUMÉ: Courant 2018, le comité Européen de normalisation des normes d'exécution géotechniques (CEN TC288) a publié une version révisée de la norme EN 12716, norme d'exécution du jet grouting. Cette révision remplace la version précédente de 2001 qui, après 17 ans d'utilisation, était en retard dans la refonte, compte tenu des énormes progrès technologiques réalisés en matière de conception, d'exécution, de contrôle de la qualité et de la vaste expérience acquise en jet-grouting au cours de cette longue période.
Les principaux changements et amendements par rapport à la version précédente ont été développés et discutés par une équipe de 16 experts de 12 pays européens. Ces experts ont non seulement rappelé l'état actuel des connaissances en matière de jet grouting et ajouté les contenus manquants, mais ont également réussi à condenser considérablement le texte. De nouvelles annexes ont été développées, principalement sur la manière de déterminer la résistance du matériau de jet grouting, ainsi que sur les essais et les enregistrements à effectuer pour obtenir une bonne qualité du procédé.
Cela a abouti à des exigences plus strictes en matière de contrôle de la qualité, notamment l'enregistrement numérique en temps réel de tous les paramètres d'exécution ainsi que des fréquences de mesures de verticalité dépendantes de la profondeur. Les auteurs de cet article sont le rédacteur en chef et un rédacteur technique du

groupe de travail d'experts du CEN TC 288 qui ont participé à cette révision de la norme. Ils expliquent les modifications apportées à la norme.

Keywords: EN 12716, jet grouting, material strength, sample quality class, logarithmic normal distribution

1 DEVELOPMENT OF JET GROUTING OVER THE RECENT PAST

Jet grouting came to Europe in the 70ties of the last century as a completely new and fascinating technology in geotechnical engineering allowing for new solutions and applications not seen before. Despite the fact that plant and equipment of that time allowed only for the creation of elements with diameters of little more than 1 m and this only up to limited depth, producing large elements through small boreholes in a large variety of soil types pushed the limits of what was possible significantly. Experiences with the quality of the product with respect to homogeneity and material strength were limited, consequently application limits and design approaches were chosen very conservatively.

However, within a couple of years quick advances and sufficient successful applications resulted in first national recommendations, guidelines and regulations for the method, e.g. the first General Technical Approval (Allgemeine bauaufsichtliche Zulassung) by the German Institute for Building Technology (Deutsches Institut für Bautechnik DIBt) on the 1st of August 1986. This marked the first step to the incorporation into the list of known and accepted technologies in Europe.

The first generation of a European execution standard was developed and published in 2001. As can be expected for a technology still quite “young” at that time, this was just an intermediate step. Since then, as a result of continuous innovation, optimisation as well as evolution of plant and equipment, enormous progress has been made. Today’s state of the art with much stronger pumps and hydraulically optimised monitors (the device containing the nozzles transforming pressure into kinetic energy) allows to produce large elements with diameters above 5 m and to install them at great depth far beyond 50 m.

The electronic controls of modern rigs enables the creation of complex geometrical forms and shapes, also in combination with directional drilling. Digitisation in data recording and analysis results in a quantum leap in quality control and safety. All this transformed the specialist technology of the early days into the “swiss army knife” of today’s geotechnical world that helps to solve all kind of problems safely and efficiently.

2 WHY THE REVISION WAS NECESSARY

Although EN 12716:2001 was an important step in the development and application of jet grouting, it was far from being perfect. It had some gaps, inadequacies and outright mistakes. The main criticism resulted from missing clear regulations for the determination of the material strength (unconfined compressive strength) so that the parties involved in a project often developed their own approaches and rules varying arbitrarily. Those rules, when compared to each other, were conflicting e.g. in how isolated low outlier values were considered and as a consequence design values calculated that way would differ by a factor of 2 or more, an untenable situation.

The figures contained in the standard also wrongly showed e.g. structures for sealing applications with gaps clearly not fit for the intended purpose. In some parts of the text the wording was rather a textbook than a short and concise instruction for minimum requirements and recommendations as one would expect in a standard code. In contrary to that, requirements for soil investigation, design, execution and quality control were often vague and gave too much room for outlandish interpretations.

The revised text is intended to overcome those shortcomings and inadequacies and is also aimed at assisting the revision of EN 1997 currently in progress. The clear intention is, that in combination with the future release of EN 1997, it should form a comprehensive basis for design and execution.

3 HOW EXECUTION STANDARDS ARE REVISED

European execution standards in geotechnical engineering are developed and revised within CEN by the Technical Committee 288 (TC288). At regular intervals of 5 years all existing standards are subject to a so-called “Systematic Review” where the need for changes is assessed and which is concluded with a formal voting. In 2013 this voting stated the need for a revision and consequently Working Group 17 (WG17) has been established and tasked with that goal. The authors of this paper took on the roles of Convenor and Technical Editor of this working group. In total 16 competent and expert members representing the most important countries within CEN as well as notable contractors and consultants with expertise in jet grouting and operating in the main European markets formed WG17.

Table 1. Delegates of CEN TC 288’s WG17

Role	**Name**	**Country**
Convenor	Gebhard Dausch	DE
Editor	Paul Pandrea	DE
Secretary	Izabella Liero	DE
Members	Robert Essler	UK
	Dr. Albert Hartmann	DE
	Maurizio Siepi	IT
	Markus Sovaleinen	FI
	Johann Blumfalk	SE
	Herard van Zwieten	NL
	Hugo Hons	BE
	Basil Leconte	FR
	Philippe Mercier	FR
	Dr. Klaus Meinhard	AT
	Arne S. Simonsen	NO
	Lars Hoksrud	NO
	Duncan Moore	CH

For the revision the members of WG17 set themselves the goals of removing errors within the text and the figures, reducing the length of the standard by streamlining and condensing its content by omitting textbook sequences and adding missing content. The new standard has now 23 pages instead of 26 (without annexes), comes without any figures, but contains a number of new annexes dealing with material strength, sample quality and quality control.

4 CHANGES INCORPORATED INTO THE REVISED STANDARD

4.1 Clause 2 “Normative references“

As can be expected from a revision of a 17 year old standard, many changes had to be made to update all normative references. For many standards listed in the 2001 version there are updates and revisions available. In addition to that, many standards for the materials and substances used in jet grouting have been included as well as a number of new test standards.

4.2 Clause 3 “Terms and Definitions“

All definitions have been streamlined like the basic definition of jet grouting itself, which is now defined as *“hydraulic disaggregation of the* *soil or weak rock and its mixing with, and partial replacement by grout"* (3.1). In the note to this definition the minimum pressure for jet grouting is defined as 25 MPa or 250 bar for a clear distinction from other grouting technologies described in EN 12715 (currently under revision in WG 18 of CEN TC 288). In (3.3) to (3.5) the new terms "sub-vertical" (all inclinations ±20° from vertical), "sub-horizontal" (all inclinations ±20° from horizontal) and "inclined" (all other inclinations) have been introduced.

The definitions of the different variants of jet grouting contained in (3.7) to (3.9) for "single system", "double system" and "triple system" are now in line with the common use of the term in the industry and consider now also the type of rods and tools used rather than only the way of working. "Jet piles" have been included as a completely new variant as proposed by the Norwegian members of WG17. For jet piles, a cavity is greated by means of jet grouting, which is then filled with concrete through a tremie pipe replacing the fluid mix of soil and water present in the cavity after the jetting procedure.

A complete new term has been indtroduced with "sample quality class", taken from the Austrian Recommendations for the Solidification of Soil (Merkblatt für Bodenvermörtelung, 2012). This takes into account that the resulting values for the unconfined compressive strength are highly dependent on the quality of the samples subjected to testing and those in turn are highly dependent on the method of sampling itself. Experience shows that particularly in obtaining samples from core drilling there is a huge ramdom impact of the "human factor" (rig operator). Prior to testing the samples, their suitability has now to be examined and clasified in 4 classes A to D.

Figure 1. Example for a sample of quality class A (suitable)

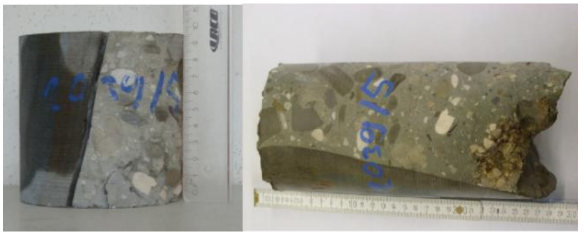

Figure 2. Example for a sample of quality class D (unsuitable)

If a sampling method does not deliver suitable samples for testing, rather the method of sampling shall be questioned and replaced by a more appropriate method than assessing the quality of the jet grouting elements based on poor samples and shedding unnecessary doubt on the quality of the product.

With the "geotechnical equivalent zones" (3.23) a new term has been introduced, which brings a new method-related view on the subsoil conditions into the standard. An equivalent zone is an area in the subsoil comprising one or more soil layers, where one set of production parameters will produce the same uniform results.

4.3 Clause 4 "Information needed for the execution of the work"

This clause has been expanded to accommodate more relevant and important details. Table 1 from 2001 has been replaced by the sub-clauses "General" and "Specific Requirements". Instead of a vague textbook-like description, there are now detailed lists that can and should be used as checklists. As construction law and responsibilities differ from country to country, this checklist does not allocated the responsibility for individual items to one of the parties involved in the project. It just states, what needs to be provided as information as a minimum for proper planning, design and execution of jet grouting and leaves it to contractual arrangements to allocate the responsibility to a particular party.

However, as in most countries soil investigation and interpretation of its results is performed by a geotechnical consultant and design is often performed by a structural engineer, they have now clearly defined work packages to accomplish.

4.4 Clause 5 "Geotechnical Investigation"

After a general reference to EN 1997 part 2 and in analogy to the previous clause there are now two sub-clauses, "General" and "Specific Requirements", which list all geotechnical conditions to be investigated, analysed and assessed during soil investigation. For jet grouting this is particularly important, more than in some other technologies, as the soil forms an integral part of the final product as an aggregate and determines the product quality (strength, stiffness, homogeneity, permeability) to a large extent.

Much more attention has been dedicated to groundwater conditions, which have a significant impact on the execution of jet grouting works. The result is another set of checklists giving clear and precise instructions to the parties involved in a project about what needs to be done. As projects involving jet grouting works fall at least into geotechnical category 2 according to EN 1997 part 1 and more often than not should be even assigned to the geotechnical category 3, the demand for a high quality soil investigation becomes obvious.

4.5 Clause 6 "Materials and products"

Also the requirements and instructions in this clause have been clarified and supplemented with references to corresponding product and quality standards to eliminate ambiguity and improve the applicability.

In doing this, no range for the water-cement-ratio has been given. This is intentional to allow for project specific adaptations like for example pre-cutting with a highly diluted grout for chemical pre-conditioning of soils to compensate for agents present in the soil potentially hampering curing and strength development (e.g. organic acids).

The requirements of clause 6.1.2 ask for mandatory tracking and documentation of the sources and supply channels of the materials used in jet grouting to allow to investigate and delimit problems related to insufficient material quality of binders that are observed in practical applications from time to time.

4.6 Clause 7 "Considerations related to design"

EN 12716 is an execution standard, nevertheless it comes with a clause "design". This may be surprising from an outside point of view, but the reason for this is that design is much more than just calculations for stability and serviceability but comprises all steps and considerations that constitute a comprehensive execution plan. This may start with the decision whether the jet grouting structure is permanent or temporary and end with a suitable installation sequence for the individual elements. Design considerations also include method specific issues like whether the borehole collars are located above or below the groundwater table and the need for test elements and their numbers.

Some clauses have been taken from the German DIN 4093:2015-11. 7.1.3 (borehole collars below groundwater table), 7.1.4 (physical properties), 7.1.7 (previous experience) and 7.1.8 (test elements) have been copied directly. Others, like 7.1.1 (applications), 7.1.2 (location of borehole collars relative the groundwater table), 7.1.6 (execution sequence) and 7.1.9 (aggressive environments) have a similar meaning. Clause 7.1.10 explicitly states, that for determination of material strength, only samples of quality class A and B shall be used.

For the numerical calculation of the value of the unconfined compressive strength a statistical approach is proposed. Annex A describes a methodology based on the assumption that the material strength has a logarithmic normal distribution.

$$f_{m,k} \leq \eta_d \cdot \exp\left(m_y - k_n \cdot s_y\right) \qquad (1)$$

$f_{m,k}$ = characteristic value of the unconfined compressive strength
η_d = factor for uncertainties not covered by other factors.
m_y = mean value of the natural logarithm of the individual values
k_n = factor for the level of reliability (1,28 for the 10%-fractile)
s_y= standard deviation of the natural logarithm of the individual values

$$f_{m,d} = \alpha \cdot f_{m,k}/\gamma_m \qquad (2)$$

$f_{m,d}$ = design value of the unconfined compressive strength
α = factor for long term effects (0.85 equal to α_{cc} from EN 1992-1-1 is recommended)
$f_{m,k}$ = characteristic value of the unconfined compressive strength
γ_m = partial safety factor for the material (1.5 for DS-P and DS-T and 1.25 for DS-A)

The precondition for the application of this statistical method is, that at least 10 samples have been tested. In case of less available values, the minimum value is the characteristic value. From a safety perspective this incentivises, and correctly so, to perform significantly more than just the bare minimum of tests to have a better and more meaningful picture of the product quality.

Annex A is an element of the revised standard that very likely will become part of the future part 3 of EN 1997 in some form. Once that has been completed, this annex A could be withdrawn to eliminate duplications.

The two figures of the previous release showing a foundation for a footing and an underpinning have been removed as they do no longer represent the state of the art and had textbook character.

Sub-clause 7.2 “Geometry” now also deals with tolerances. The working group chose to use the values given in EN 14199 (micropiles) in its annex B as the drilling methods and rigs used for micropiles and jet grouting are quite similar. This was necessary as even today many designs can be found where inevitable tolerances have not been considered resulting in solutions that either cannot be implemented safely or are not fit for purpose.

Few changes were necessary in clause 8.3 “Strength and deformation characteristics” and it could be used almost without any amendments. The issue of permeability could be condensed into two short sentences.

4.7 Clause 8 “Execution”

The fact that the high pressure within the jet grouting system is only used to generate the high velocity jet and shall not be misinterpreted as a grouting pressure is now a numbered clause and thus upgraded in its importance.

In clause 8.1.4 “alternative execution methods” one can now find not only pre-cutting but also other methods including the already mentioned “jet piles”. The clause about the method statement now gives a clear and precise table of content to make sure all relevant issues are covered on the one hand and to avoid lengthy textbooks on the other hand. To date EN 12716 is the only execution standard giving this level of detail for the content of a method statement as a description of the intended way of execution. Nevertheless, execution parameters mentioned in the method statement can always be just an indicative starting point and have to be verified and eventually adapted on site according to the findings during execution and examination of the test columns.

Clause 8.3.2 now explicitly demands for working platforms, that their bearing capacity shall be proven according to EN 1997-1 (base failure) for loads and pressures from drilling rigs calculated in accordance with EN 16228-1 annex F. This is now the first time that explicit and precise instructions for the design of working platforms have been made in an execution standard for the benefit of the safety on site.

4.8 Clause 9 "Supervision, testing and monitoring"

This clause has been revised extensively as particularly in this area enormous technical progress has been made and consequently the need for change was significant. Clause 9 makes a reference to annex C where in table C.1 there is a very detailed list of all direct and indirect tests to be performed including the frequency of testing. This annex is now normative and as such a requirement and not just a recommendation.

Particularly important changes are:

(1) There have to be tested 4 samples for every 500 m³ of jet grouting produced in non-cohesive soils and for every 250 m³ of jet grouting produced in cohesive soil in contrast to the 4 samples every 1000 m³ until now.

(2) Verticality measurements are now required for one in 10 boreholes for a depth greater than 10 m and for every single borehole for depths greater than 30 m.

(3) Recording of production parameters has to happen electronically and continuously in real time. Manual records in the aftermath of production are allowed only as an exception for short periods of system failure.

In doing this EN 12716 lays the foundation for a digital recording of all production parameters and thus provides the base for creating as-built BIM modles through appropriate electronic interfaces for project specific databases. In that way, jet grouitng becomes fit for BIM.

4.9 Clause 10 "Records"

This clause replaces the former clause "Execution documents" and is more precise in many ways. Particularly the requirements for the amount of information to be shown in execution drawings as well as the quality of their visualisation is a significant step forward. It is now mandatory to include information about subsoil and groundwater conditions and they have to be displayed adjusted to the right level and shown in the same scale as the cross sections to be executed for the avoidance of errors and misunderstandings. Drawings shall be sources of information and instruct people on site, not riddles.

5 CONCLUSIONS AND CONSEQUENCES FOR THE EXECUTION OF JET GROUTING

The revised version of EN 12716 is a significant upgrade when compared to the release from 2001 and the current state of the art for jet grouting is now much better represented. The revision also achieved to condense and streamline its content and eliminate textbook passages to be more user friendly and precise. In doing this the revised standard is much more a clear instruction for all parties involved in a jet grouting project than a general description of jet grouting.

The deletion of the drawings also eliminated the mistakes there and in turn many clauses are much more precise and exact and leave less room for interpretation. Contractors, consultants and designers have much better instructions and guidance now and it should be much easier to allocate responsibilities without prescribing them. In doing this, the need for additional national standards, regulations, guidelines and recommendations should have been reduced significantly.

With annexes A and B substantial contributions have been made to the revision of EN 1997 that is currently performed by CEN TC250 SC7 in its working groups, task groups and project teams. Ideally they can be incorporated without any changes to their wording without triggering a substantial need for future changes to EN 12716 itself so that the new release should be fit for purpose for a longer period and well behind the estimated release date fo the revised EN 1997.

The authors want to thank the international team of experts for the productive, constructive and colaborative work in the working group. The discussions we had over the years were fruitfull and even if contradicting views were brought forward the mutal respect and kindness was always there so that there was sufficient room for compromise and we all were able to learn from each other. It may sound awkward to say something like this about a committee for European standards, but working together as an international team to improve this standard for the benefit of the whole jet grouting community was fun.

6 REFERENCES

EN 1997-1:2009-09 “Eurocode 7: Geotechnical Design – Part 1: General Rules”

EN 1997-2:2010-10 „Eurocode 7: Geotechnical Design – Part 2: Ground investigation and testing”

EN 12716:2001-12 “Execution of special geotechnical works – Jet Grouting”

EN 12716 (draft) “Execution of special geotechnical works – Jet Grouting”

EN 14199:2012-01 “Execution of special geotechnical works – Micropiles”

DIN 4093:2015-11 “Design of strengthened soil – Set up my means of jet grouting, deep mixing and grouting”

Merkblatt „Qualitätssicherung für Bodenvermörtelung“ der Österreichischen Bautechnik Vereinigung, September 2012

Allgemeine bauaufsichtliche Zulassung Nr. Z-34.4-1, 1. August 1986