Hansbo, S. and Massarsch, K. R. 2005. Standardisation of Deep Mixing Methods. Proceedings, Intern. Conf. On Deep Mixing, Stockholm, 23 – 25 May, 2005. Vol. 1, pp. 3 - 10.

Standardisation of Deep Mixing Methods

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ABSTRACT: This paper describes the objectives and main aspects of the code on "Execution of special geotechnical works — Deep mixing" (prEN 14679). The standard establishes general principles for the execution, testing, supervision and monitoring of deep mixing works. Both dry and wet methods by rotary mixing are included in the standard. In two annexes, Practical aspects of deep mixing (A) and Aspects of design (B), additional information is provided.

1 INTRODUCTION

In 1975, the Commission of the European Community initiated a programme to produce a set of technical codes, which in the future could serve as an alternative to existing national codes and eventually replace them. In 1989, the Commission decided to transfer the preparation and publication of the Eurocodes to the European Committee for Standardization (CEN). CEN, whose members are National Standard Bodies (NSBs), was founded in 1961 by the national standards bodies in the European Economic Community and EFTA countries.

Ten Eurocodes are presently in different phases of preparation. All Eurocodes were initially published as trial codes, known as ENVs. A minimum of two years after publication of each ENV, NSBs submitted comments on its contents and use. In many cases, the final EN will be significantly different from corresponding ENVs. Following the publication of the Eurocodes together with its National Annexes, there will be a period (known as the coexistence period), during which they can be used alongside the existing national codes. At the end of the coexistence period, which may last a maximum of three years, NSBs are required to withdraw their national standards.

NSBs are not permitted to change any part of the text in the Code Document. However, it is recognised that the level of safety in a country remains its prerogative. Consequently, some safety factors and a number of other parameters, such as those reflecting differences in climatic and geological conditions, are left open in the Eurocodes for selection at a national level. These are termed Nationally Determined Parameters (NTPs). The National Annex of each Eurocode lists the NTPs and other points on which an element of national choice exists. The National Annex may also include reference to non-conflicting complimentary information (NCCI) such as national standards or guidance documents.

2 GEOTECHNICAL EUROCODES

In many European countries, the introduction of the Eurocode on Geotechnical Design, EN 1997 will represent a marked change in practice. EN 1997 – Geotechnical design, consists of two parts (international publication dates indicated in brackets):

- EN 1997-1: Geotechnical Design Part 1 – General Rules (End 2005)
- EN 1997-2: Ground investigation and testing (2006?).

The European Federation of Foundation Contractors, (EFFC) has, on behalf of CEN, prepared codes on "Execution of Special Geotechnical Works". CEN Working Group TC 288 covers execution aspects, which are not addressed in EN 1997. They are being developed independently of EN 1997 and focus on the practical application of a selected number of geotechnical construction methods. Since Eurocode EN 1997 covers geotechnical design, these aspects are addressed in the Application Codes only where execution affects the design. At the time of preparation of this paper, the following seven codes have been approved (international publication dates indicated in brackets):

- EN 1536: Bored Piles (Feb 1999)
- EN 1538: Diaphragm Walls (Jan 2000)
- EN 1537: Anchors (Dec 1999)
- EN 12063: Sheet Piles (Feb 1999)
- EN 12699: Displacement Piles (Dec 2000)
- EN 12715: Grouting (July 2000)
- EN 12716: Jet Grouting (May 2001).

In addition, the following six codes are presently under preparation, subjected to national inquiries or submitted for formal voting (anticipated date of international publication indicated in brackets):

- prEN 14199: Micro-Piles (2004)
- prEN 14475: Reinforced Soil (2004)
- prEN 14490: Soil Nailing (2004)
- prEN 14679: Deep Soil Mixing (2005)
- prEN xxxxx: Vertical Drainage (2005)
- prEN 14731: Deep Vibration (2006).

3 CODE ON DEEP MIXING

This paper describes the objectives and main aspects of the code on "Execution of special geotechnical works — Deep mixing" (prEN 14679), which was prepared by Working Group 10 of CEN/TC288. The implementation of this standard was sponsored by the Development Fund of the Swedish Construction Industry (SBUF), who nominated the Technical Editor (Sven Hansbo) and Convenor (K. Rainer Massarsch). Work was started in 2000 and experts from 9 European countries participated. Also members of a Japanese Mirror Group have taken part in the preparation of the draft document and contributed with their extensive experience. The work was also followed by several European mirror groups. The draft was prepared within less than three years and submitted to national inquiry in 2003. After revision of the document, taking into consideration the comments by the NSBs, the standard is now being submitted to CEN member countries for formal approval.

The objective of the code is to establish general principles for the execution, testing, supervision and monitoring of deep mixing works. Both dry and wet mixing methods are included in the standard, Figure 1.

a) Dry mixing b) Wet mixing

Figure 1. Examples of dry and wet mixing machines.

The document consists of the following main chapters:

1. Scope
2. Normative References
3. Terms and definitions
4. Information Needed for the Execution of the work
5. Geotechnical Investigation
6. Materials and Products
7. Considerations related to Design
8. Execution
9. Supervision, Testing and Monitoring
10. Records
11. Special Requirements.

The standard contains also two informative Annexes:

- *Annex A:* Practical aspects of deep mixing
- *Annex B*: Aspects of design.

4 CONTENTS OF THE CODE

4.1 Scope

As an introduction to the document, chapter one, *Scope*, addresses the relevance and limitations of deep mixing. The code covers dry mixing and wet mixing methods executed by means of rotating mechanical mixing tools. Other methods, such as shallow mixing or hybrid methods (e.g. combination of mixing and jet grouting or mixing by other than rotary tools), are not covered. Stabilized elements can have different shapes and configurations, but must have a minimum depth of 3 m.

4.2 Normative References

In the second chapter, *Normative References, o*ther applicable codes and standards are given.

4.3 Terms and Definitions

The third chapter lists in alphabetic order (English) deep mixing terms in English, French and German. The terms are defined, in order to clarify their relevance and to facilitate the understanding of the provisions pf the code. The degree of obligations of the provisions can have the following levels: "Requirements" (the verb *shall* is used), "Recommendations" (the verb *should* is used), "Permissions" and "Possibilities" (the verb *can* is used), and "Statements" (informative text).

4.4 Information needed for the execution of the work

This chapter discusses the most important provisions required for planning and implementing a deep mixing project. All provisions given are requirements and divided into *General Requirements* and *Particular Requirements*. Information, which must be provided before the execution of the work, is listed.

The General Requirements comprise definitions of environmental conditions, e.g. restrictions on noise, vibrations, pollution and conditions of structures, roads, services, etc. adjacent to the work. The Particular Requirements include documentation of previous experience and of possible underground contamination and a definition of the instructions that have to be given for the work.

4.5 Geotechnical Investigation

Chapter 5, *Geotechnical Investigation*, addresses information that is of importance for the execution of the work, e.g. identification and classification of the soil in compliance with EN ISO 14688-1-2, mapping of any kind of obstacles to be expected during deep mixing (e.g. tree roots, cobbles, boulders, cemented layers, etc.) and information about the variations in piezometric level.

It is also recommended that the environmental chemical and biological characteristics should be stated, e.g. groundwater quality (contamination, aggressiveness, chemistry, etc.).

4.6 Materials and products

Chapter 6 deals with admixtures, water, filler and structural reinforcement. It is required that all material and products used comply with relevant European or national standards. They must conform also to national environmental regulations and design specifications. Water must be suitable for the intended use.

4.7 Considerations related to design

The goal of the provisions in chapter 7 is to create deep-mixed columns and structures having the maximum strength and minimum load-deformation characteristics possible under prevailing soil conditions at the site. In the design, loading conditions, climatic effects, hydraulic conditions, acceptable limits of settlement have to be taken into account. Possible consequences of chemical and physical exposure of the columns have to be considered.

The properties of the binder selected for the project must be investigated by laboratory and *in-situ* tests of the treated soil. If deep mixing is used to immobilise contaminants or to stabilise waste deposits, site-specific test programmes are required.

Important details should be stated in the design, such as performance objectives, geometry of the treatment and specification of the deep mixing materials or products selected. Moreover, a schedule of testing and monitoring procedures during execution as well as acceptance procedures for the materials used should be provided.

Limiting values of geotechnical design parameters shall be stated and steps to be taken if these values are exceeded. General design aspects, however, are not addressed by the code, as they are covered by EN 1997.

4.8 Execution

Aspects of *Execution* are discussed in chapter 8. Before the execution of deep mixing, a method statement shall be delivered, which among other matters includes the objective and scope of the work, the deep mixing method and the binder to be used, the working procedure and the installation accuracy.

The site of deep mixing has to be prepared in order to create suitable access for plant and equipment. A working platform has to be created with adequate bearing capacity for equipment, receipt, quality control and storage of material.

When experience of previous, comparable deep mixing project is not available, representative field trials must be performed in order to confirm that the design requirements can be fulfilled.

The execution control of deep mixing includes penetration and retrieval speed of the mixing tool, rotation speed of the mixing units, air pressure in dry mixing and feed rate of binder/slurry.

The equipment and the mixing tool shall be correctly positioned at each column location in accordance with the geometrical execution tolerances specified in the design. The quantity of binder along the column shall be measured during installation of each column. In *dry mixing* the air pressure shall be kept as low as possible to avoid problems of air entrainment and ground movement. In *wet mixing* the slurry shall be delivered by pumping in a continuous flow to the soil to be treated. In both cases the speed of the rotating unit(s) and the rate of penetration and retrieval of the mixing tool shall be adjusted to produce sufficiently homogeneous treated soil.

In some cases, structural reinforcement may have to be installed into the fresh mixed-in-place columns or elements.

4.9 Supervision, testing and monitoring

Quality control aspects are addressed in chapter 9. The deep mixing work shall be supervised by experienced and qualified personnel. Unforeseen conditions encountered during the work have to be reported in order that the problems can be taken care of.

Testing of the strength characteristics, the deformation properties and the homogeneity of the columns is essential and shall be performed continuously during the work to check that the agreement with the design assumptions is acceptable. If overlap of adjacent columns is essential, the width of overlapping must be checked. In connection with immobilisation and containment, relevant chemical tests should be carried out.

The execution shall be monitored, preferably automatically, with regard to air tank pressure or, in wet mixing, slurry pressure, penetration and retrieval rate, rotation speed and quantity of binder (slurry) per meter of installation.

4.10 Records

Relevant information as to the construction execution of the columns, test results and observations during the work shall be available at the site. After completion of the work, details regarding the as-built columns, material and products used and relevant geotechnical soil conditions shall be left on record.

4.11 Special requirements

The special requirements deal with the safety of personnel operating close to heavy equipment and heavy tools. Environmental restrictions and consequential environmental protection are other objects to be taken into account, including noise, vibrations, pollution of air and water and impact on adjacent structures.

4.12 Annex A - Practical aspects of Deep Mixing

Annex A, which supplements the code, deals with practical aspects of deep mixing projects. It contains a historical review of the development of the deep mixing methods and a presentation of the fields of application. The generic classification of the equipment is shown in Figure 2.

A variety of applications for deep mixing exists for temporary or permanent works either on land or marine, Figure 3. A detailed description is given of the various execution methods and equipments utilised as well as the purpose behind the application of deep mixing and the princi-

ples of execution. Nordic and Japanese dry mixing techniques are compared in detail as well as European and Japanese wet mixing techniques. Various possible execution patterns of installation applied are shown.

Dry mixing is normally carried out in accordance with general principles, which are summarised in Figure 4. As can be seen in the flow chart, the binder is fed into the soil in dry form with the aid of compressed air. Two major techniques for dry mixing exist at present: the Nordic and the Japanese techniques.

Finally, construction problems, such as possible stability and settlement problems, chemical reactions and personnel safety are taken into consideration.

Annex A contains also examples of so-called *hybrid methods*, not covered by the code, for example *mass stabilisation* (a method of surface mixing, used in Sweden and Finland), Jet grouting combined with mechanical mixing and the CDM-LOD IC method (both these methods used in Japan) and, finally the Cut-Mix-Injection (used in Germany).

4.13 Annex B - Aspects of Design

Annex B deals with overall aspects related to functional and process design, choice of binder, laboratory and field testing and influence on the design of column layout and performance.

The object of design is to make sure that the ground treated fulfils the requirements for the intended purpose of deep mixing. Supported structures shall be fit for use during their intended life with appropriate degree of reliability and sustain all actions and influences that are likely to occur during execution and use. Iterative design, based on a follow-up of the results obtained by testing during the execution period, is an important part of the design.

The requirements for the serviceability and ultimate limit states are to be specified by the client. The design shall be in accordance with the requirements put forward in ENV 1997-1, Eurocode 7: Geotechnical design — Part 1: General rules.

So-called iterative design, based on a follow-up of the results obtained by various testing methods, is an important part of the design. Here, the main focus is placed upon those factors that are important for the execution and the purpose of deep mixing. The design is made for the most unfavourable combinations of loads, which could occur during construction and service.

The deep mixing process may involve a short-term decreasing resistance to failure in consequence of induced excess pore water pressure and soil displacements. The mixed-in-place columns should be arranged in a way to avoid that possible planes of weakness in some columns installed could have a negative influence on the stability. In the stability analysis it is important to take into account the differences in stress vs. strain relationship between treated and untreated soil. For excavation support, the most important parameters are the compressive strength of the treated soil and arching. Figure 5 indicates the iterative process combining functional design and process design.

A presentation is made of the execution process and of the choice of binder in dry and wet mixing of various kinds of soil. Testing on a laboratory scale of laboratory mixed samples is carried out before the execution of deep mixing in order to find out which binder to be used to achieve the strength and deformation characteristics required for the intended structure.

During execution, both laboratory and field testing methods are used to investigate if the homogeneity and strength characteristics of the columns are satisfactory. The deformation properties of the columns are investigated on a laboratory scale.

Finally, an overall presentation of the problems involved in the design with regard to how the settlement process is affected by deep mixing on one hand and how stability problems can be treated on the other. Problems like column separation; structural wall and block type applications are discussed.

5 ACKNOWLEDGEMENTS

The standard on deep mixing was prepared by WG 10 of the CEN Technical Committee TC288. The following nine experts have contributed to the successful and efficient preparation of this document: Dr. E. Falk (Austria), Mr. I. Vähäaho (Finland), Mr. S. Lebon (France), Mr. P. Scheller (Germany), Mrs. R. Granata (Italy), Mrs. A. Eggen (Norway), Mr. D. M. Moore (Switzerland), Dr. H. L. Eriksson (Sweden) and Mr. V. Troughton (United Kingdom).

The members of a Japanese Mirror Group, Dr. Masaki Kitazume and Dr. Masaaki Terashi, have taken part in the preparation of the draft document and contributed with their extensive experience. The work has also been followed by several European mirror groups. Gratitude is also extended to the national mirror groups, which attended meetings and reviewed the draft documents.

The work of preparing the standard was sponsored by the European Federation of Foundation Contractors (EFFC), the Swedish Federation of Foundation Contractors and the Swedish Construction Industry (SBUF). Their support is acknowledged with appreciation.

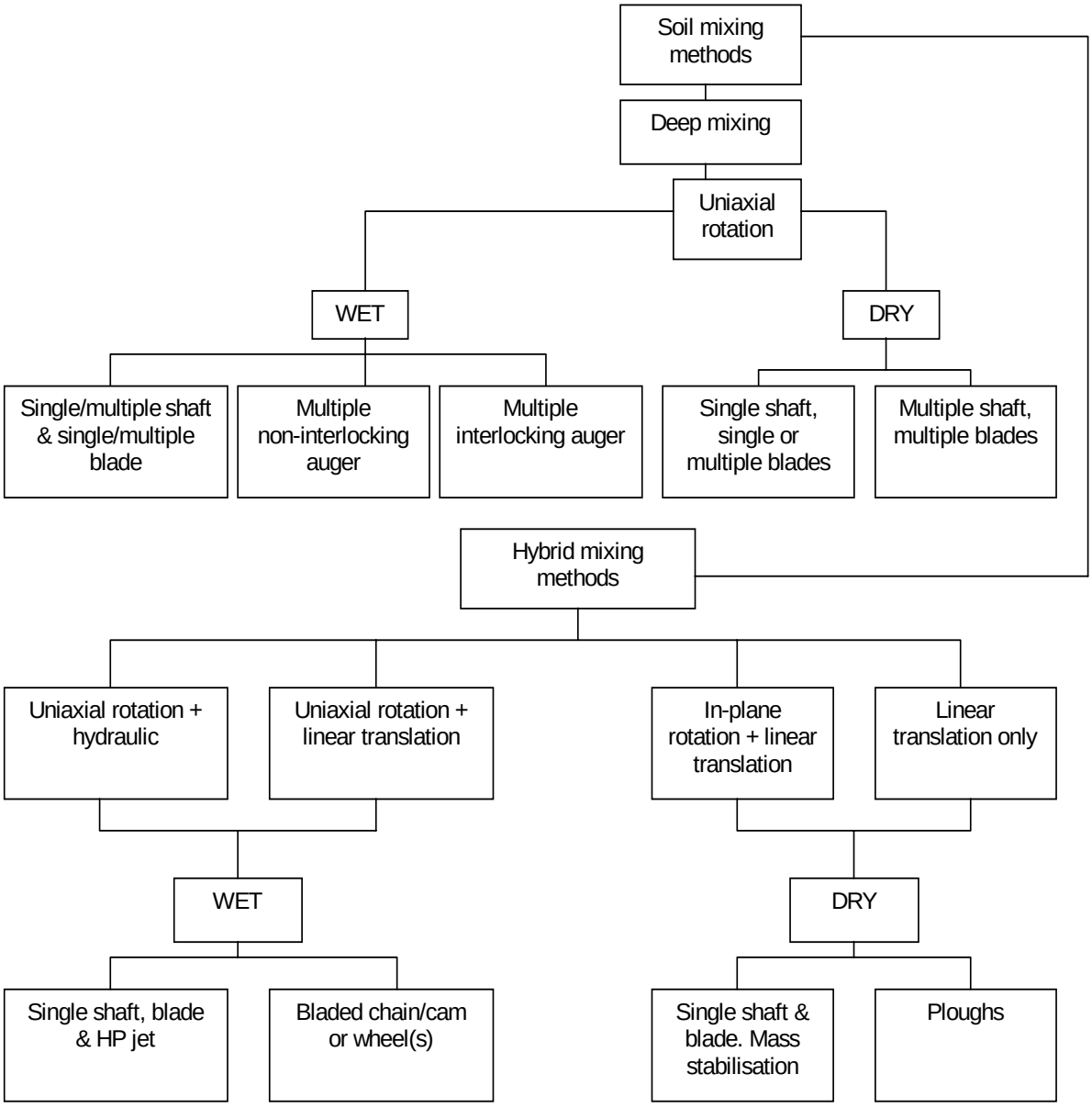

Figure 2. General classification of equipment used by the deep mixing methods included in the Code and by hybrid mixing methods not included.

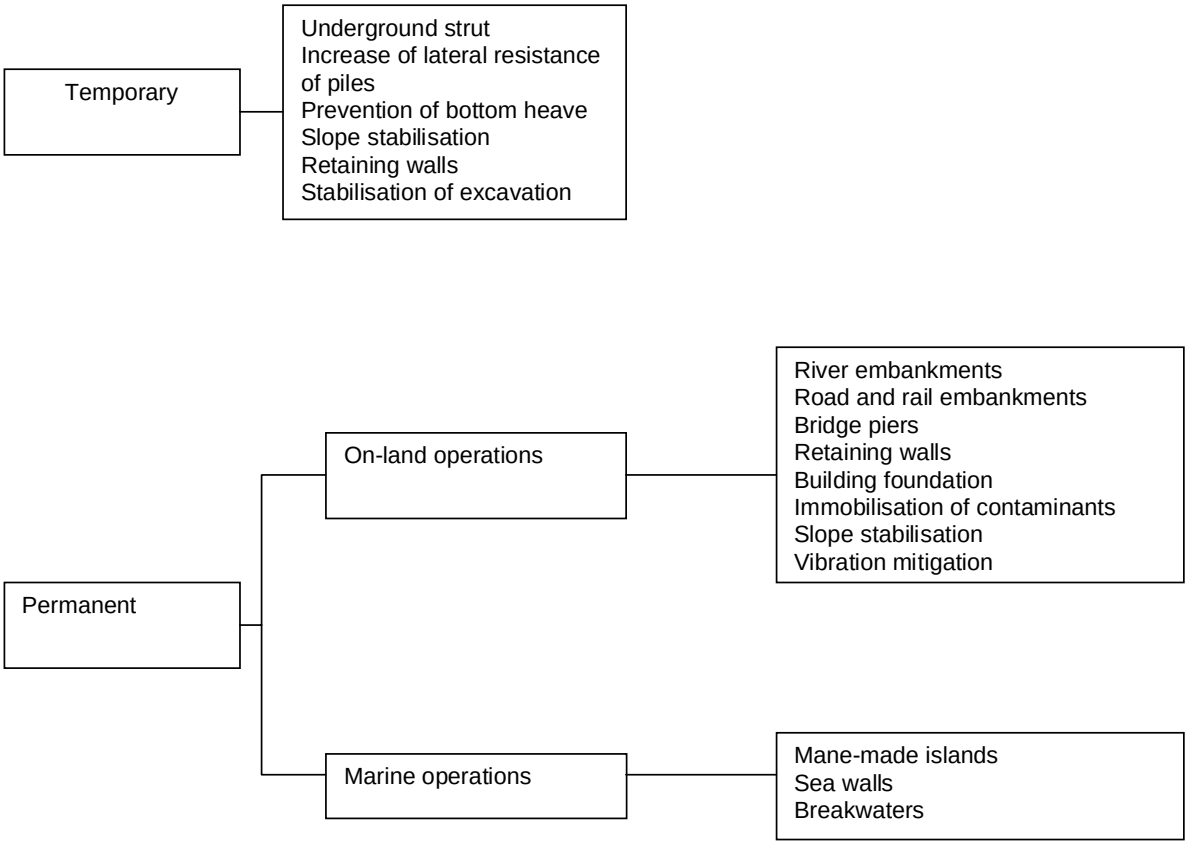

Figure 3. Applications of deep mixing for various purposes.

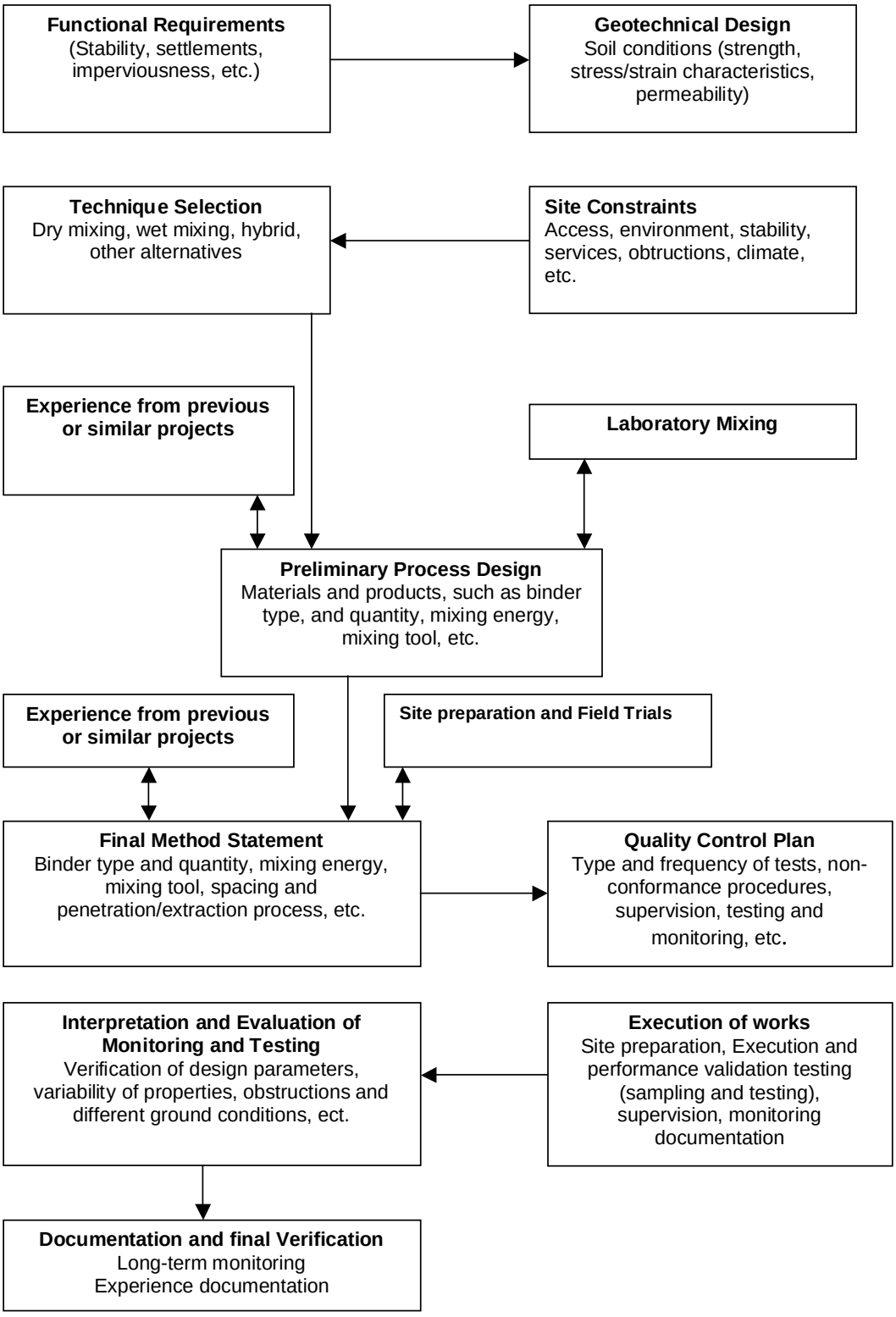

Figure 4. Principles of execution of deep mixing.

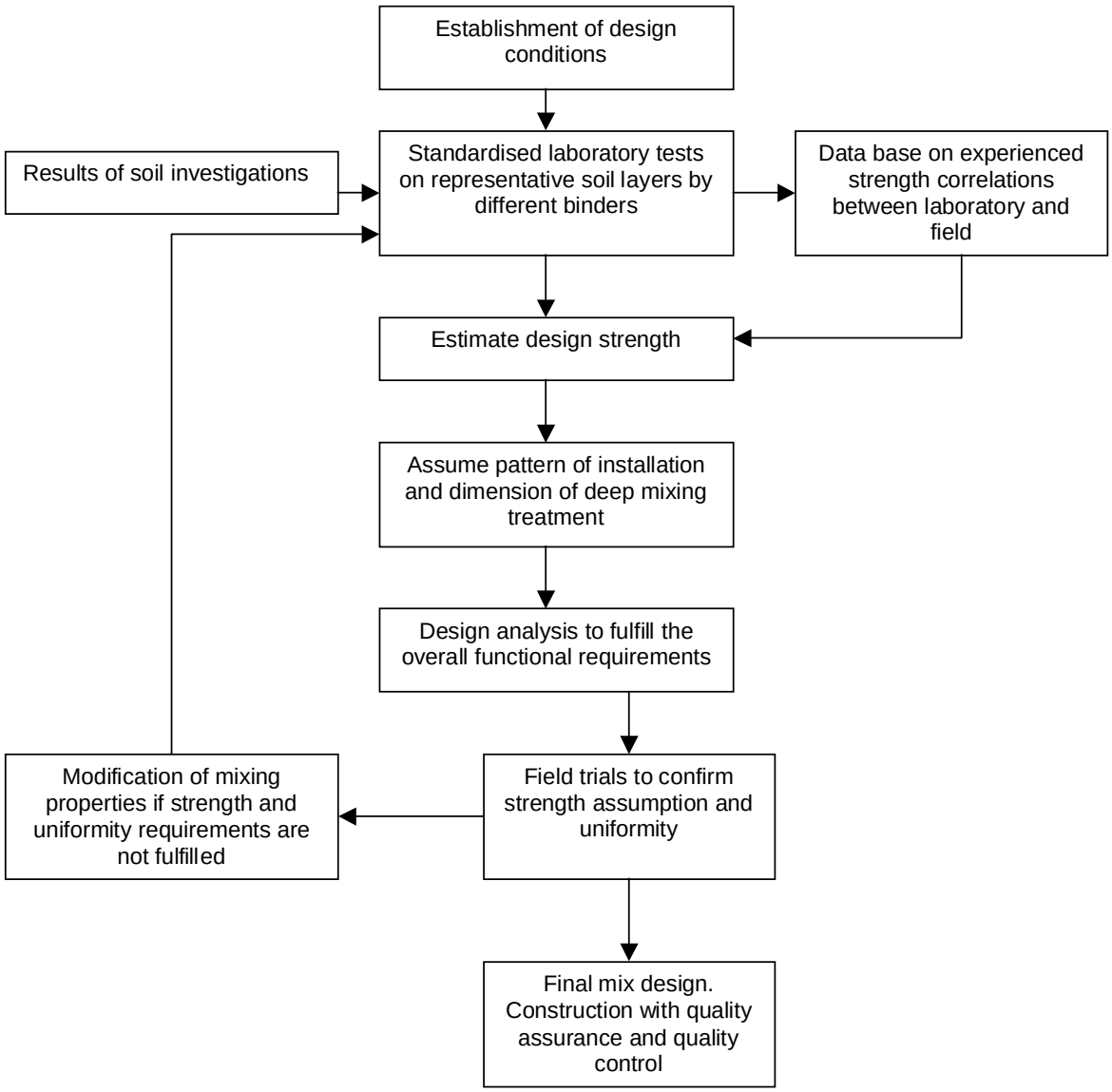

Figure 5. Iterative design process, including laboratory testing, functional design, field trials and process design.