

Introduction to DIN 4871: Qualification of NDT Personnel in Civil Engineering (NDT-CE)

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Abstract

Recently, non-destructive testing in civil engineering (NDT-CE), in particular of concrete components, has successfully mastered the leap from research to practice. Several methods have been established for field inspections to determine the concrete cover of reinforcement or to estimate the compressive strength as well as other parameters related to the concrete material. In addition, the application of non-destructive testing is indispensable, if information about the inner structure - such as the location of rebars and tendon ducts or the damage-related condition assessment to detect grouting defects, honeycombs, delamination, or corrosion - is required. Besides the selection of a suitable NDT method and an appropriate inspection system, the reliability of the results depends largely on the person who applies the non-destructive inspection technique and evaluates the inspection results. To ensure a high quality of non-destructive concrete evaluation as well as to keep the uncertainty caused by the inspection personnel to a minimum, structured, consistent, and regulated theoretical as well as practical training of inspection personnel is essential. To close this gap, the subcommittee of education and training (UA-A) within the committee for NDT-CE of the German Society for Non-Destructive Testing (DGZfP) has been reactivated in 2018 to establish uniform training standards for non-destructive concrete inspections in the long term. The subcommittee consists of scientists, practitioners, authorities, and clients. So far, the national standard DIN 4871 “Non-destructive testing - Qualification of NDT personnel in Civil Engineering (NDT-CE)” was developed. This standard considers the civil-industry-specifics, for example, that standards for NDT of concrete, as well as related product standards with a few exceptions, still do not exist at the moment. Within this presentation, the concept, the connection to ISO 9712 and other standards as well as an overview of the recently developed German standard DIN 4871 will be presented.

Keywords: NDT-CE; DIN 4871; Personnel; Qualification; Training; Education; Standard; Modules; Syllabus;

1 Introduction

The inspection of relevant infrastructure such as bridges becomes more relevant due to the ageing process and the increased traffic load. Therefore, gaining reliable information is essential to ensure the safety of civil structures. Besides the visual inspection, non-destructive testing



methods such as the rebound hammer or magneto-inductive methods are well established in the industry to determine the concrete cover or to estimate the concrete compressive strength. In addition, also emerging techniques such as ground penetrating radar (GPR), ultrasonics or impact echo are more often used to gain knowledge about the inner structure and to detect or quantify damages such as honeycombs and delaminations.

To be as precise and reliable as possible, the performance of the inspection system containing the inspection technique, the inspection procedure, and the inspection personnel has to be well known. Therefore, valuable tools such as the GUM (Guide to the Expression of Uncertainty in Measurement) [1] or the POD (Probability of Detection) [2], [3] were successfully transferred to non-destructive testing in civil engineering (NDT-CE) several years ago [4], [5].

However, the reliability of the results depends not only on the selection of a suitable inspection method and a suitable inspection system, but also to a large extent on the personnel who apply the non-destructive testing methods. To become indispensable for the monitoring of the manufacturing process or the periodic in-service inspection of concrete components, standardized qualification and certification of personnel is required in addition to concrete-specific method-related and product-related standards to keep the uncertainty caused by the inspection personnel as small as possible. This leads to the conclusion, that uniform and standardized education and training for inspection personnel would be valuable.

The aim of the subcommittee for education and training (UA-A) within the committee for NDT-CE of the German Society for Non-destructive Testing (DGZfP), which was reactivated in 2018, was to establish uniform training standards for the non-destructive testing of concrete and reinforced concrete (NDT-CE) in the long term. DIN EN ISO 9712 [6] is currently not used in the civil industry sector, since on the one hand, it does not fully cover all the methods used. On the other hand, the basic requirement for including the civil industry sector in the ISO 9712 - a complete NDT-CE method-standardization - is not fulfilled. These circumstances must be taken into account for the work in this subcommittee to anchor the application of non-destructive testing methods and the usability of test results evaluated by personnel in the field during the whole life of a concrete structure.

After several meetings of intensive discussions about a goal-oriented approach considering the diverse experience of experts from the industry, research institutes and practitioners it was decided to submit an application for the establishment of a standardization project to the standards committee for Materials Testing (NA 062) of the German Institute for Standardization DIN (DIN NMP). After preparing a roadmap and a draft of the standard for the qualification of NDT-CE personnel, in 2020 a vote took place in the DIN NMP that approved the establishment of a national standardization project. So based on the draft, the work on the standard DIN 4871 “Non-destructive testing – Qualification of NDT personnel in Civil Engineering (NDT-CE)” could be started in June 2020 with the support of the organisations represented in Figure 1. The expected timeline was to not exceed the duration of 3 years from the beginning of the project until the final publication of the standard.



Figure 1: Organizations working on DIN 4871

2 DIN 4871 – Overview, Scope and Content

Considering the lack of standardization for nearly all concrete inspection methods as well as the missing link between NDT-CE and concrete-related standards, the idea of the developed standard is to define the minimum amount of training for NDT-CE inspection personnel in the civil industry. Therefore the DIN 4871 [9] connects the idea of the two internationally relevant standards for inspection personnel - the ISO 9712 [6] (“formal aspects”) and the ISO 25107 (“training syllabuses”) [7] - and adapts them to the civil industry.

Other specifics of the civil industry such as individual constructions, cheap concrete materials and the associated destructive extraction of information as well as the limited financial resources have also been considered during the definition of regulations. In addition, it is also important to avoid parallel or contradictory regulation in the civil industry and therefore take also existing standards - such as the DIN 1076 [8] for bridge inspections or the training under the roof of the GfKORR (*Gesellschaft für Korrosionsschutz e.V.* - Society for Corrosion Protection) - into account.

Based on these boundary conditions as well as on the typical inspection tasks in the field, the following inspection methods were identified to be standardized in so-called **method-related modules** regarding theoretical and practical training contents recognizing the points mentioned above (see [9] chapter 1):

- a. Rebound hammer
- b. Magneto-inductive methods
- c. Potential mapping
- d. Ground penetrating radar
- e. Ultrasonics
- f. Impact-echo

Since some inspection tasks in the civil industry are frequently requested and carried out, two **inspection task-related modules** were defined:

- g. Proof of compressive strength
- h. Proof of reinforcement

To also cover the basic knowledge, which is required before applying different inspection methods, **basic modules** were also established, which have to be completed during the qualification:

- Overview of non-destructive testing in civil engineering
- Measurement technology
- Wave theory and physical basics
- Damage mechanisms and structural specifics
- Quality assurance
- Combination of inspection methods

An overview about the general structure of DIN 4871 is given in Figure 2 ([9] chapter 1).

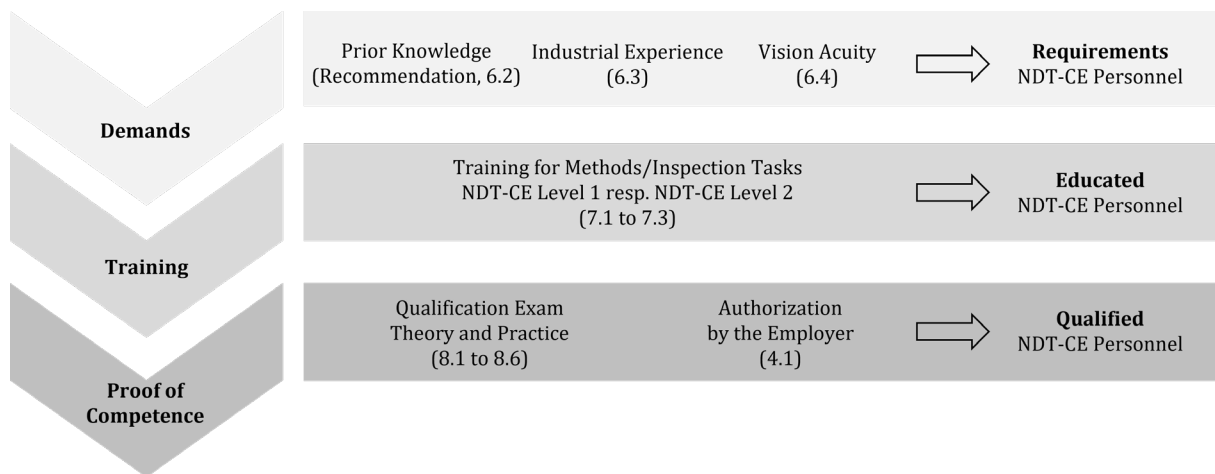


Figure 2: Overview over the regulated contents of DIN 4871

The most important chapters of DIN 4871 [9] are listed below:

- Scope; normative references; terms and definitions
- Responsibilities of employer, examination centre and examiners
- Levels of qualification (NDT-CE Level 1 and NDT-CE Level 2)
- Eligibility (general aspects, prior knowledge, industrial experience, vision acuity)
- Training (general aspects, amount of training, modules)
- Examinations (general aspects, theoretical and practical examination, evaluation, ...)
- Appendix A (theoretical training contents for the NDT-CE method-related modules)
- Appendix B (theoretical training contents for the NDT-CE inspection task-modules)
- Appendix C (theoretical training contents for the NDT-CE basic modules)
- Appendix D - informative (practical training contents for the NDT-CE method- and inspection task-related modules)

3 DIN 4871 – Level Definition of NDT-CE Inspection Personnel

After an intensive discussion about an adequate definition of levels for the civil industry, considering both, the ISO 9712 level definition and the specifics of the civil industry, the subcommittee concluded, that two levels fulfil these criteria and represent the relevant inspection tasks of NDT-CE inspection personnel in the field in contrast to the three levels defined in ISO 9712 (compare subchapter 3.1/3.2).

3.1 NDT-CE Level 1

From the subcommittees point of view, the main purpose of NDT-CE Level 1 personnel to be performed in the field is the data acquisition with its related tasks. Therefore, the following definition was created (see [9] chapter 5.1; **Please note:** currently not yet officially translated; this translation was provided by the authors of this paper):

“A person qualified in NDT-CE Level 1 has demonstrated the ability to perform NDT-CE in accordance with a procedure and under the supervision of NDT-CE Level 2 inspection personnel. NDT-CE Level 1 personnel must be operationally authorized by their employer within the specified scope to perform the following in accordance with procedures:



- a) *Adjustment of NDT-CE equipment in accordance with procedures.*
- b) *Execution of measurements and their adjustment to the boundary conditions.*
- c) *Recording of measurement results as well as their preliminary evaluation and classification based on written criteria.*
- d) *Report on measurement results to NDT-CE Level 2 inspection personnel.*

NDT-CE Level 1 personnel are not permitted to make a selection of the inspection method or the inspection technique, nor are they take responsibility for the final evaluation and assessment.”

3.2 NDT-CE Level 2

From the subcommittee’s point of view, the main purpose of NDT-CE Level 2 personnel to be performed in the field is the data evaluation with its related tasks and the supervision of NDT-CE Level 1 personnel. Therefore, the following definition was created (see [9] chapter 5.2; **Please note:** currently not yet officially translated; this translation was provided by the authors of this paper):

“A person qualified in NDT-CE Level 2 has demonstrated the ability to perform and supervise NDT-CE activities. The NDT-CE Level 2 inspection personnel may perform operationally authorized the following activities within the specified scope:

- (a) All NDT-CE Level 1 activities.*
- (b) Guidance of NDT-CE level 1 inspection personnel.*
- (c) Selection of the inspection method and the inspection technique as well as determining the limit of application.*
- (d) Development of procedure and interpretation of standards, regulations, and guidelines.*
- (e) Supervision of measurements.*
- (f) Evaluation and assessment of measurement results.*
- (g) Documentation.*
- (h) Technical responsibility for the inspection result generated from the measurements and their evaluation.”*

4 DIN 4871 – Requirements

Beside specifying an approach containing theoretical and practical training to ensure comparable competence in the application of NDT-CE and to be able to evaluate these competencies, one main goal of introducing a standard was to keep the entry barrier to NDT-CE as low as reasonable. Therefore, a minimum set of requirements were defined regarding prior knowledge and industrial NDT-CE experience (see [9] chapter 6). Accordingly DIN 4871 recommends to demonstrate prior knowledge of the candidate through a technical vocational training or a relevant study prior to the training. The minimum industrial NDT-CE experience before the training must be as indicated in Table 1 at the time of training. If a candidate seeks training in more than one inspection method or inspection task, the industrial NDT-CE experience time must equal the sum of the industrial NDT-CE experience times in each inspection method or inspection task.

Table 1: Minimum industrial NDT-CE Experience

| NDT-CE Method or NDT-CE Inspection Task | Industrial NDT-CE Experience in days ^a | |
|---|---|----------------|
| | NDT-CE Level 1 | NDT-CE Level 2 |
| Rebound Hammer | 5 | 20 |
| Magneto-inductive Methods | 10 | 30 |
| Potential Mapping | 10 | 30 |
| Ground Penetrating Radar | 10 | 30 |
| Ultrasonics | 10 | 30 |
| Impact-Echo | 10 | 30 |
| Proof of Compressive Strength | 15 | 30 |
| Proof of Reinforcement | 15 | 30 |

^a One-day duration is at least seven hours, which can be achieved on a single day or by accumulating hours. The maximum allowable hours in any one day is 12 hours. Experience in days is achieved by dividing the total accumulated hours by 7.

In addition, the candidate shall provide documentary evidence of acceptable vision in accordance with the employer's requirements. Depending on the inspection method or inspection task, near vision acuity and, if applicable, color vision has to be tested. The employer shall document the requirements in writing.

5 DIN 4871 – Training

The minimum duration of training is given in Table 2 for the respective inspection method or inspection task (see [9] chapter 7). The duration is based on the candidate having adequate mathematical skills and knowledge of material properties and manufacturing processes. Training includes both practical and theoretical elements.

Table 2: Minimum Training Requirements

| NDT-CE Method or NDT-CE Inspection Task | Training Amount in days ^a | |
|---|--------------------------------------|----------------|
| | NDT-CE Level 1 | NDT-CE Level 2 |
| Rebound Hammer | 1 | 2 |
| Magneto-inductive Methods | 2 | 2 |
| Potential Mapping | 1 | 2 |
| Ground Penetrating Radar | 2 | 2 |
| Ultrasonics | 2 | 2 |
| Impact-Echo | 2 | 2 |
| Proof of Compressive Strength | 2 | 2 |
| Proof of Reinforcement | 2 | 2 |

^a One-day duration is at least seven hours, which can be achieved on a single day or by accumulating hours. The maximum allowable hours in any one day is 12 hours. Experience in days is achieved by dividing the total accumulated hours by 7.

Prior to the initial qualification for an NDT-CE Level 1, the one-day basic module “Overview of non-destructive testing in civil engineering” has to be completed.

Before the initial qualification for an NDT-CE Level 2, the basic modules according to Table 3 must be completed.

Table 3: Minimum Training Requirements for the Basic Modules NDT-CE Level 2

| Basic Modules for NDT-CE Level 2 | Training Amount in days ^a |
|---|--------------------------------------|
| Measurement Technology | 1 |
| Wave Theory and Physical Basics | 1 |
| Damage Mechanisms and Constructive Specifics | 1 |
| Quality Assurance | 1 |
| Combination of Inspection Methods | 1 |
| Overall | 5 |
| ^a One-day duration is at least seven hours, which can be achieved on a single day or by accumulating hours. The maximum allowable hours in any one day is 12 hours. Experience in days is achieved by dividing the total accumulated hours by 7. | |

6 DIN 4871 – Examination

The qualification examination (see [9] chapter 8) consists of a theoretical and a practical element and must cover a specific NDT-CE inspection method or a specific NDT-CE inspection task. Theoretical and practical qualification exams must be supervised by an examiner, who has to meet certain requirements (see [9], chapter 4.3). The theoretical and practical parts of the examination must be evaluated separately.

6.1 Theoretical Examination

The theoretical exam may only consist of multiple-choice examination questions randomly selected from the collection of questions for qualification exams. These questions must be confirmed and approved by an examiner. A minimum number of multiple-choice examination questions specified in DIN 4871 have to be answered by the candidate. The theoretical qualification exam is considered passed if the candidate achieves a score of at least 70%.

6.2 Practical Examination

In practical exams, the NDT-CE Level 1 candidate must demonstrate his ability to perform and to document NDT on a test specimen unknown to him. The NDT-CE Level 2 candidate must also demonstrate his ability to evaluate and assess measurement results and to prepare a procedure.

The practical exam must include the application of the inspection method or inspection task for the specified test specimens and the recording of the results. The practical exam must be performed on areas of test specimens whose test situation differs from the test situations during training. For the test specimens used for the qualification exams, documentation must be available containing the geometry as well as the properties relevant to the respective inspection task in a representative manner. During the practical exam, the NDT-CE Level 1 candidate has to follow the procedure provided by the examiner. The NDT-CE Level 2 candidate has to select

an NDT-CE method suitable for the inspection task and define the procedure in relation to given regulations, standards or specifications. In addition, NDT-CE Level 2 candidates shall design at least one procedure appropriate for NDT-CE Level 1 personnel for a test specimen selected by the examiner. The practical qualification exam is considered passed if the candidate achieves a score of at least 70%.

7 DIN 4871 – Syllabus Example (Rebound Hammer)

For each inspection method and inspection task as well as for the basic modules contents for theoretical and practical training were defined (see [9] Appendix A, B, C and D). The basic concept will be introduced in the following subchapters on the example of the Rebound Hammer.

7.1 Theoretical Training Contents on the Example of the Rebound Hammer

For each inspection method and inspection task a syllabus containing the theoretical aspects was created according to the scheme introduced with ISO/TS 25107 [7], see Table 4.

Table 4: Basic Scheme of the theoretical Training Contents

| Theoretical Contents for the method-related and the inspection-task related Modules |
|---|
| 1. Introduction to Terminology and historical Background |
| 2. Physical Principle |
| 3. Product Knowledge (Correlation between Method and Product, Method Capabilities and Limitations) |
| 4. Equipment |
| 5. Information prior Data Acquisition |
| 6. Data Acquisition |
| 7. Data Evaluation, Interpretation and Documentation |
| 8. Assessment and Inspection Statement |
| 9. Quality Assurance |
| 10. New Developments |

For the example of the method-related module “Rebound Hammer”, the developed syllabus covering the theory can be found in Table 5, taken from [9] Appendix A.1.

Table 5: Theoretical Contents of the Rebound Hammer Module (normative)

| Contents of the theoretical NDT-CE Method Training | | | |
|--|--|-----------------------|-----------------------|
| Rebound Hammer | | | |
| Contents | | NDT-CE Level 1 | NDT-CE Level 2 |
| A.1.1 Introduction to Terminology and historical Background | Historical Development of the Methods | X | |
| | Tasks of the NDT-CE personnel | X | X |
| | Standards and Guidelines | X | X |
| | Hardness, Compressive Strength, Carbonation | X | X |
| | Hardness Testing, Spring Hammer, Rebound Hammer | X | X |
| A.1.2 Physical Principle | Measurement Principles and Impact Energy (Rebound Distance und Quotient of Velocity) | X | |
| | Correlation Hardness – Compressive Strength Correlation Rebound Hammer – Cores Depth of Influence, Correlation Curves, Correlation Tables, Regressions | X | |
| | Core Taking (Basic Idea, Requirements such as Number, Geometry, etc.) | X | |
| A.1.3 Product Knowledge (Correlation between Method and Product, Method Capabilities and Limitations) | Rebound Values and Compressive Strengths, comparative Measurements with the Rebound Hammer | X | X |
| | Factors affecting the Measurement Result (a. o. Carbonation, Gravitation, Friction, Component Thickness, Surface, Moisture, Temperature, Load, Aggregates, etc.) | X | X |
| | Options: only Rebound Hammer without Cores; Correlation of Rebound Hammer and Cores; Only Cores | X | X |
| | Component Properties and Parameters affecting the Concrete Quality (a.o. Hardness, Compressive Strength, Effect of Frost and Weathering) | X | X |
| A.1.4 Equipment | Rebound Hammer (compliant with Standards: with R- and Q-Values), Anvil, Grinding Stone | X | |
| | Cores (Requirements and Taking) | X | |
| A.1.5 Information prior Data Acquisition | Aim of the Inspection | X | X |
| | Carbonation State, Year of Construction (Structure or Component) | X | |
| | Inspection Area and Surface Condition | X | |
| A.1.6 Data Acquisition | Standards for the Data Acquisition | X | X |
| | Definitions, Inspection Conditions, Functional Checks | X | |
| | Requirements for the Number of Measurements | X | |
| | Data Acquisition with the Rebound Hammer | X | |
| | Taking Cores | X | |
| | Determination of the Carbonation Depth | X | |

| Contents of the theoretical NDT-CE Method Training Rebound Hammer | | | |
|--|--|---------------------------|---------------------------|
| Contents | | NDT-CE Level 1 | NDT-CE Level 2 |
| A.1.7 Data Evaluation, Interpretation and Documentation | Standards for the Data Evaluation | X | X |
| | Definitions, Overview about the different Evaluation Approaches | X | X |
| | Comparative Evaluation (Rebound Hammer) | | X |
| | Evaluation with Correlation Curves and Correlation Tables | | X |
| | Evaluation in Correlation with Cores | | X |
| | Destructive Compressive Strength Estimation | | X |
| A.1.8 Assessment and Inspection Statement | Comparison of the Results with additional Information (a. o. Soundings, Plans, Drawings) | | X |
| | Concept of Compressive Strength Evaluation | | X |
| | Compressive Strength Evaluation based on Results gained from non-destructive Tests with Correlation Curves and -tables | | X |
| | Compressive Strength Evaluation based on the Combination of Results gained from destructive and non-destructive Tests | | X |
| | Compressive Strength Evaluation based on Results gained from destructive Tests | | X |
| | Localization of Concrete Qualities and -Differences | | X |
| | Inspection Report | | X |
| A.1.9 Quality Assurance | Concept and essential Parts of Procedures | X | X |
| | Application of Procedures | X | |
| | Development of Procedures | | X |
| | Creation of Tender Contents | | X |
| | Additional Investigations | | X |
| | Further Quality Assurance Measures | | X |
| | Examples for Laboratory and in-situ Measurements and Inspections | X | X |
| A.1.10 New Developments | Automated Data Evaluation | | X |
| | Additional Concepts such as the Combination or Ultrasonics and Rebound Hammer (SONREB) | | X |
| | New Approaches from Research and Development | | X |

7.2 Theoretical Training Contents on the Example of the Rebound Hammer

The minimum requirements for practical Rebound Hammer training are exemplarily summarized in Table 6, taken from [9] Appendix D.1.

Table 6: Practical Contents of the Rebound Hammer Module (informative)

| Contents of the practical NDT-CE Method Training | | |
|--|--|---|
| Rebound Hammer | | |
| Inspection Task | Requirements | Tasks |
| D.1.1 Concrete Compressive Strength Estimation applying Rebound Hammer and/or Cores | <ul style="list-style-type: none"> — Calibration Anvil — Set of Rebound Hammers measuring the Rebound Distance (R-Value) and the Quotient of Velocity (Q-Value) — Concrete Test Block with a minimum Thickness of 10 cm (better of 30 cm minimum) with smooth Surface (horizontal and vertical) — Suitable Pairs of Values to calculate a Regression Curve | <ul style="list-style-type: none"> — Calibration at the Anvil — Determination of R- and Q-Values — Differences of R- and Q-Values gained on horizontal and vertical Surfaces considering the Impact Direction — Calculation of a Regression Curve from given Measurement Data supported by a software |
| D.1.2 Detection of qualitative Differences in Concrete Compressive Strength | <ul style="list-style-type: none"> — Calibration Anvil — Set of Rebound Hammers measuring the Rebound Distance (R-Value) and the Quotient of Velocity (Q-Value) — Concrete Test Block or in-situ Component with obviously different Concrete Compressive Strengths | <ul style="list-style-type: none"> — Calibration at the Anvil — Application of Rebound Hammers (R- and Q-Values) and capture the qualitative Differences of the measured Values |

It has to be considered, that the minimum requirements for theoretical training are normative whereas the practical training contents are informative due to the complexity of test block manufacturing.

8 Summary and Outlook

In more than 25 meetings during the last years, the subcommittee of education and training (UA-A) within the committee for NDT-CE of the German Society for Non-Destructive Testing (DGZfP) has developed the first standard for the training and qualification of personnel in Civil Engineering (NDT-CE). Members of different organisations such as service providers, universities, or research institutes containing scientists, practitioners, authorities, and clients were actively involved to comply with the national standardization project “DIN 4871” under the roof of the standards committee for Materials Testing (NA 062) within the German Institute for Standardization DIN (DIN NMP).

The German national standard DIN 4871 has passed the mandatory objection period in November 2021. All submitted comments have been addressed, so an official release can be expected in August 2022.

Soon, an official translation of DIN 4871 into English is in preparation. Furthermore, an additional standard - DIN 4873: “Non-destructive testing - Certification of NDT personnel in Civil Engineering (NDT-CE)” - is planned to establish a certification process for NDT-CE inspection personnel by an independent body.

Please note, that all excerpts taken from DIN 4871 [9] are currently not yet officially translated. The presented translation was provided by the authors of this paper.



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