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Standard Guide for Acoustic Emission Examination of Concrete Structures[1]

This standard is issued under the fixed designation E3100; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide describes the application of acoustic emission (AE) technology for examination of concrete and reinforced concrete structures during or after construction, or in service.

1.2 Structures under consideration include but are not limited to buildings, bridges, hydraulic structures, tunnels, decks, pre/post-tensioned (PT) structures, piers, nuclear containment units, storage tanks, and associated structural elements.

1.3 AE examinations may be conducted periodically (short-term) or monitored continuously (long-term), under normal service conditions or under specially designed loading procedures. Examples of typical examinations are the detection of growing cracks in structures or their elements under normal service conditions or during controlled load testing, long term monitoring of pre-stressed cables, and establishing safe operational loads.

1.4 AE examination results are achieved through detection, location, and characterization of active AE sources within concrete and reinforced concrete. Such sources include micro- and macro-crack development in concrete due to loading scenarios such as fatigue, overload, settlement, impact, seismicity, fire and explosion, and also environmental effects such as temperature gradients and internal or external chemical attack (such as sulfate attack and alkali-silica reaction) or radiation. Other AE source mechanisms include corrosion of rebar or other metal parts, corrosion and rupture of cables in pre-stressed concrete, as well as friction due to structural movement or instability, or both.

1.5 This guide discusses selection of the AE apparatus, setup, system performance verification, detection and processing of concrete damage related AE activity. The guide also provides approaches that may be used in analysis and interpretation of acoustic emission data, assessment of examination results and establishing accept/reject criteria.

1.6 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E543 Specification for Agencies Performing Nondestructive Testing

E1316 Terminology for Nondestructive Examinations

E1932 Guide for Acoustic Emission Examination of Small Parts

E2374 Guide for Acoustic Emission System Performance Verification

2.2 *ANSI/ASNT Standards:*[3]

SNT-TC-1A Recommended Practice for Nondestructive Testing Personnel Qualification and Certification

ANSI/ASNT CP-189 Standard for Qualification and Certification of Nondestructive Testing Personnel

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[1] This guide is under the jurisdiction of ASTM Committee E07 on Nondestructive Testing and is the direct responsibility of Subcommittee E07.04 on Acoustic Emission Method.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

2.3 *AIA Standard:*[4]

NAS-410 Certification and Qualification of Nondestructive Personnel (Quality Assurance Committee)

2.4 *ISO Standard:*[5]

ISO 9712 Non-Destructive Testing-Qualification and Certification of NDT Personnel

2.5 *ACI Documents:*[6]

ACI 228.2R-13 Report on Nondestructive Test Methods for Evaluation of Concrete in Structures

ACI 228.1R-03 In-Place Methods to Estimate Concrete Strength

ACI 437R-03 Strength Evaluation of Existing Concrete Buildings

3. Terminology

3.1 *Definitions*—See Terminology E1316 for terminology related to this guide.

4. Summary of Guide

4.1 The guide describes the process of AE examination of concrete structures and discusses selection of the AE apparatus, setup, system performance verification, detection and processing of concrete damage related signals.

5. Significance and Use

5.1 Real-time detection and assessment of cracks and other flaws in concrete structures is of great importance. A number of methods have been developed and standardized in recent decades for non-destructive evaluation of concrete structures as well as methods for in-place evaluation of concrete properties. Review of some of these methods can be found in ACI 228.2R-13, ACI 228.1R-03, and ACI 437R-03. They include visual inspection, stress-wave methods such as impact echo, pulse velocity, impulse response, nuclear methods, active and passive infrared thermography, ground-penetrating radar and others. These methods in most of the cases are not used for overall inspection of the concrete structure due to limited accessibility, significant thickness of concrete components, or other reasons and are not applied for continuous long-term monitoring. Further, these methods cannot be utilized for estimation of flaw propagation rate or evaluation of flaw sensitivity to operational level loads or environmental changes, or both.

5.2 In addition to the previously mentioned non-destructive tests methods, vibration, displacement, tilt, shock, strain monitoring, and other methods have been applied to monitor, periodically or continuously, various factors that can affect the integrity of concrete structures during operation. However, these methods monitor risk factors that are not necessarily associated with actual damage accumulation in the monitored structures.

5.3 Monitoring the opening or elongation of existing cracks can be performed as well using different technologies. These may include moving scales (Fig. 1), vibrating wire, draw wire, or other crack opening displacement meters, optical and digital microscopes, strain gages, or visual assessment. However, this type of monitoring is only applicable to surface cracks and requires long monitoring periods.

5.4 This guide is meant to be used for development of acoustic emission applications related to examination and monitoring of concrete and reinforced concrete structures.

5.5 Acoustic emission technology can provide additional information regarding condition of concrete structures compared to the methods described in sections 5.1 – 5.3. For

[4] Available from Aerospace Industries Association of America, Inc. (AIA), 1000 Wilson Blvd., Suite 1700, Arlington, VA 22209-3928, http://www.aiaaerospace.org.

[5] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[6] Available from American Concrete Institute (ACI), 38800 Country Club Dr., Farmington Hills, MI 48331-3439, http://www.concrete.org.

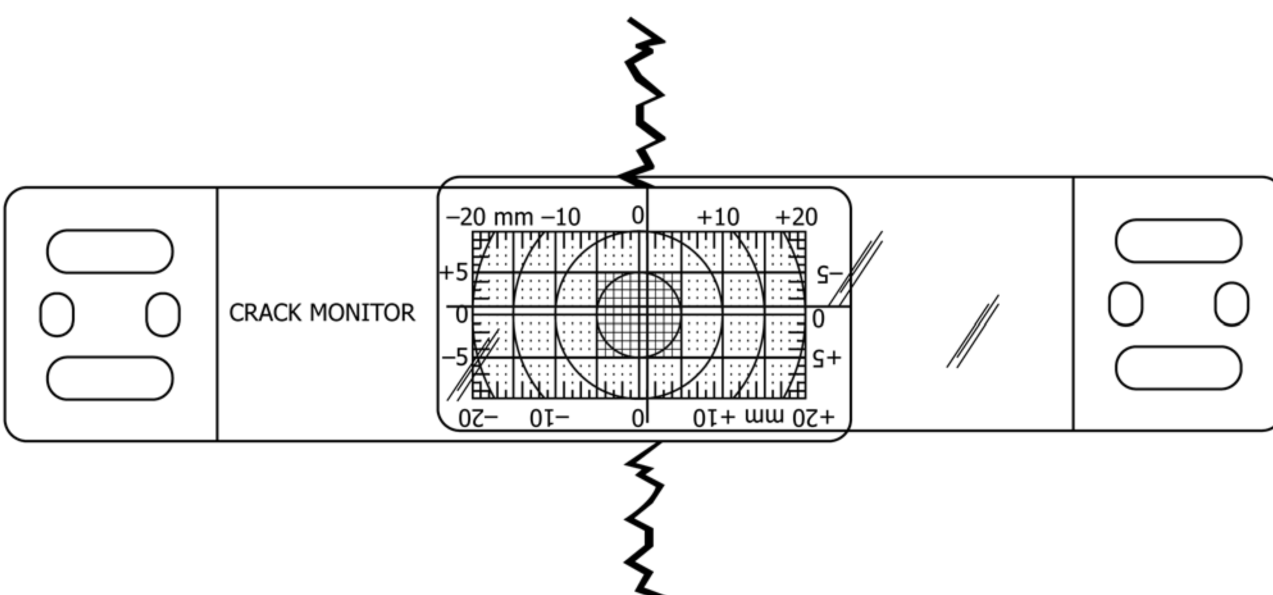

FIG. 1 Moving Scale Crack Opening Monitor

example, the acoustic emission method can be used to detect and monitor internal cracks growing in the concrete, assess crack growth rate as a function of different load or environmental conditions, or to detect concrete micro-cracking due to significant rebar corrosion.

5.6 Accuracy, robustness, and efficiency of AE procedures can be enhanced through the implementation of fundamental principles described in the guide.

6. Basis of Application

6.1 The following items are subject to contractual agreement between the parties using or referencing this guide.

6.2 *Personnel Qualification:*

6.2.1 If specified in the contractual agreement, personnel performing examinations to this guide shall be qualified in accordance with a nationally and internationally recognized NDT personnel qualification practice or standard such as ANSI/ASNT CP-189, SNT-TC-1A, NAS-410, ISO 9712, or a similar document and certified by the employer or certifying agency, as applicable. The practice or standard used and its applicable revision shall be identified in the contractual agreement between the using parties.

6.3 *Qualification of Nondestructive Testing Agencies:*

6.3.1 If specified in the contractual agreement, NDT agencies shall be qualified and evaluated as described in Specification E543. The applicable edition of Specification E543 shall be specified in the contractual agreement.

7. The Process of Acoustic Emission Examination of Concrete Structures

7.1 The process of AE examination of concrete structures includes the following principal steps. As decisions are made under these steps (7.1.1 – 7.1.4), a test procedure or instruction shall be written, based on those steps, to guide the field activities.

7.1.1 Defining the goal(s) of the examination.

7.1.2 Developing an understanding of the structure, material properties, and flaw characteristics.

7.1.3 Selection of the operational, load, and environmental conditions for conducting the examination.

7.1.4 Selection of suitable equipment and sensor installation methods.

7.1.5 System performance verification.

7.1.6 Field examination and post examination system performance verification.

7.1.7 Data analysis, interpretation, and assessment.

7.1.8 Reporting.

8. Defining Goals of the Examination

8.1 Prior to conducting an AE examination or AE structural health monitoring of a concrete structure, it is necessary to define the primary goals and the scope of the examination together with a designer or operator of the structure, or both (**1**).[7] Success of the examination is defined as the degree to which the goals of the examination is achieved.

8.2 The way in which AE technology is applied can vary with different goals. Examples of primary goals are:

8.2.1 Evaluation of known crack development under specific load conditions.

8.2.2 Characterization of mechanical and fracture mechanics properties of concrete members used in a structure.

8.2.3 Establishment of safe loads/operational conditions.

8.2.4 Prediction of ultimate loads.

8.3 Primary examination goals can be achieved when at least one or several of the following objectives are addressed:

8.3.1 Detection of active concrete cracking and other flaw-indications in the structure.

8.3.2 Location of flaw-indications.

8.3.3 Identification of flaw-indications, for example, identification of tensile or shear concrete micro-cracking, corrosion damage, and others (**2-4**).

8.3.4 Assessment of flaw-indications, for example damage qualification of reinforced concrete beams subjected to repeated loading (**3**).

8.3.5 Structural integrity diagnostics and establishment of serviceability.

8.3.6 Prediction of ultimate loads.

9. Understanding the Structure, Material Properties, and Flaw Characteristics

9.1 Correct interpretation of AE results for source mechanism identification, flaw-indication assessment and diagnostics depends on satisfactory knowledge of the examined structure, examination conditions (including environmental), understanding the material properties of the structure, manufacturing methods and material behavior under stress. Therefore, prior to an acoustic emission examination, it is recommended to obtain the following information:

9.1.1 *Structural Information:*

9.1.1.1 The function of the structure and its design including detailed drawings, if available.

9.1.1.2 Operational/stress/environmental conditions and other factors that may contribute to flaw origination and development.

9.1.1.3 Results of previous NDT examinations, including the location and nature of known flaw indications (if any).

9.1.1.4 Statistics of failures of similar structures, typical flaws, possible location of flaws and expected rate of flaw propagation.

9.1.1.5 Factors that can contribute to flaw origination and development (deformation, support instability, known or suspected design errors, etc.).

9.1.1.6 Wave propagation characteristics in the structure (propagation modes, velocities, attenuation characteristics, effects of anisotropy, etc.).

9.1.2 *Material Information:*

9.1.2.1 Materials used (concrete and reinforcing steel), related properties, manufacturing methods, and processes.

9.1.2.2 Potential failure mechanisms.

9.1.3 *Examination Conditions:*

9.1.3.1 Possible sources of noise and other conditions that may affect the examination.

[7] The boldface numbers in parentheses refer to the list of references at the end of this standard.

9.2 Laboratory or full scale tests, or both, can provide significant portions of the above required information. Tests can be conducted on specimens or structural elements, or both, such as beams, columns, or full-sized structural systems with or without flaws to develop the ability to detect, identify and assess/classify specific flaws in the target structure. Normally flawless concrete cubic or cylindrical specimens (taken from the target structure or specially prepared) are examined to better understand initiation and development of flaws up to failure and to study load bearing capabilities of materials; whereas flawed specimens are examined to study flaw-detection capabilities by AE testing or to evaluate sustainability of materials with damage. In addition, standard examination of concrete cores taken from the examined structure, together with AE measurement, is recommended to identify the condition and quality of the concrete (for example concrete uniformity or presence of internal flaws like segregations and honeycombing), identify possible concrete age related degradation, and possible deviation from the designed properties.

9.3 AE signals acquired during testing of small scale specimens can be affected by reflections, different geometric/size effects on flaw development, and other factors. Therefore, in every test it is necessary to find invariant qualitative or quantitative AE characteristics that can be usefully applied for examination of real structures. Examples of such invariant characteristics are:

9.3.1 Stress at onset of detectable AE in flawless specimens (without known flaws such as cracks or segregations).

9.3.2 Stress at onset of events related to macro-crack growth.

9.3.3 Stress at onset of damage development acceleration accompanied by acceleration of AE rate.

FIG. 2 Reinforced Column Specimen During Compression Testing

9.4 Mechanical properties acquired during specimen tests should be documented, and should include the compressive strength or load at failure, or both, at a minimum. When a statistically sufficient number of specimens are tested, it is useful to:

9.4.1 Investigate the statistical distribution of the mechanical properties and acoustic emission parameters or characteristics of the examined specimens.

9.4.2 When statistically significant groups of specimens are identified, based on similar mechanical or AE characteristics, perform fractography examinations to identify qualitative or quantitative differences between groups of specimens. Once such differences are identified, the obtained information may be used for detection of these indications in target applications.

9.5 Whenever possible, it is recommended to perform full scale tests on structures with known service developed or artificially induced flaws. Artificially developed flaws may have lower detectability compared with service developed flaws.

9.6 Obtaining the above information is required for development of appropriate examination procedures, including selection of equipment, and determining examination setup, development of assessment criteria, evaluation of flaw detectability, and reliability of examination. When partial inspection of a bridge is performed, the collected information may be used to prioritize zones for AE examination.

10. Selection of Equipment and Sensor Installation

10.1 General rules for selection of equipment described in Guide E1932 shall apply with the following additional considerations:

10.1.1 The primary consideration in selection of sensors is frequency characteristics of AE waves produced by the development of potential flaws in the examined structure.

10.1.2 Sensors sensitive in the frequency range between 20 to 250 kHz are typically applied for examination of reinforced concrete structures. Sensors sensitive in other frequency bands can be used in special cases.

10.1.3 Flat response sensors in the above mentioned frequency range may be used whenever it is necessary to perform frequency-based analysis of AE signals to separate different processes by their frequency characteristics and for performing techniques for advanced AE source location, etc.

10.2 Sensor positioning and installation should be performed under the following considerations:

10.2.1 Sensors spacing is based on investigation of wave propagation characteristics in the structural components and by AE background noise characteristics. AE velocity in concrete can vary with the concrete quality and the presence of rebar or other inclusions. Significant reduction of AE velocity locally can be the result of cracks, voids, and other significant flaws. Therefore, it is recommended to perform velocity estimation and attenuation tests in all main structural elements independently. In zones with elevated and/or variable background noise, the distance between sensors can be shortened to allow better detectability, which is one of the primary objectives of examination.

10.2.2 Sensor spacing, when full coverage of a structure is required, normally should not exceed the distance at which pencil-lead break (PLB) generated AE waves will attenuate more than 30 dB relatively to the AE amplitude of PLB performed at distance of 3 cm from the nearest sensor's edge. It is important to note that attenuation profile can be different on different concrete structures and therefore specific attenuation curve should be established in every examination case.

10.2.3 It is recommended to place sensors in zones with the highest stresses, at proximity of know flaws or at zones with high risk of flaw presence as well as at proximity of main structural joints. For monitoring of macro-cracks in concrete it is recommended to place sensors in the vicinity of the crack tips.

11. System Performance Verification

11.1 System performance verification should be conducted before beginning the examination. During the examination if any change in performance is observed, these changes should be noted, and re-verification conducted if the changes may adversely affect the examination results. A final performance verification should be conducted after completion of the examination to verify there is no change in system performance. This is to ensure the integrity and accuracy of the data being collected during examination. Particularly, the examiner must verify that sensors are properly mounted on the structure and maintain the required sensitivity level and that there are no conditions that reduce sensitivity and reliability of the system. Maximum deviation between channels, based on pencil lead break (PLB) or other artificially generated AE waves, should not exceed 3 decibels (dB). Any channels exceeding the maximum deviation or performing below required minimum threshold should be repaired or replaced. Any significant change in performance during examination should be documented. System performance verification shall be performed according to the guidelines provided in Guide E2374.

12. AE Field Examination

12.1 The optimal examination procedure is one that ensures the maximum probability of detection of a flaw/fault indication while minimizing false negatives. This can be achieved by the application of AE examination under appropriate loading or environmental conditions, or both, and using suitable equipment and methods of data acquisition, background noise reduction, and data analysis.

12.2 *Loading/Environmental Conditions for Conducting AE Examination:*

12.2.1 Optimal conditions for performing examination are considered those under which flaws/faults naturally originate and develop in the examined structure. For example, if it is assumed that flaws originate and develop in a bridge primarily due to heavy traffic, it is recommended to conduct AE examination with and without heavy traffic conditions. If cracking of a bridge support due to water freezing inside of the concrete is suspected, it is recommended to perform the AE examination during freezing and thawing conditions. Chemically induced concrete cracking due to rebar corrosion (**5-7**) or alkali-silica reaction (**8**) can result in low-level AE activity and examination in such cases may have to be performed over extended periods of time.

12.2.2 For buildings, tunnels, and other structures not exposed to changing loads, AE examinations may be performed under self-weight conditions. In such cases, only actively developing cracks due to deformation, settlement, and corrosion or other chemical processes can be detected.

12.2.3 In certain cases, an examination may be performed when loads exceed normal operational/service loads. This may occur when the duration of examination is short and additional stimulus is necessary to intensify flaw development or when a structure is periodically subjected to overstresses from vehicular overloads. Additional special examinations may be performed under controlled variable stress conditions to evaluate sensitivity of flaws to load/stress changes or establish Felicity ratio. These cases are not considered in this guide.

12.3 *Duration of an Examination:*

12.3.1 Duration of an examination can be defined based on the following considerations:

12.3.1.1 Structures such as bridges or turbine foundations or crane decks that operate under changing load conditions should be monitored during at least several load cycles. For example, in case of turbine foundations, they can be monitored during turbine startup, operation, and shutdown. Normally the operator/owner/designer of a structure can define service conditions during which to perform AE monitoring.

12.3.1.2 Structures that operate under self-weight conditions without changing stress or environmental conditions can be tested for several hours (minimum 1 hour) to detect or rule out the presence of actively developing cracks which are normally characterized by the AE rate of dozens or more AE events per hour.

12.3.1.3 Long term or continuous monitoring of a structure may be necessary when it is required to assess particular mechanisms, such as cable or strand rupture rate (**9**) or fatigue monitoring or when it is needed to assess structural integrity under seismic (**10**) or other activity related to extreme events or under differing weather conditions.

12.4 *Noise Management:*

12.4.1 Structures can operate under constantly changing conditions due to vehicular traffic, and environmental changes (wind, rain, hail, etc). These conditions may often generate high and variably changing background noise levels, and is one of the main challenges to be addressed during an AE examination. Therefore, it is recommended to avoid AE measurements under elevated noise conditions. However, since examinations may be conducted for in-service structures, a background noise check should be conducted prior to examination to determine what noise reduction efforts may be needed