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Non-destructive testing — Acoustic emission testing — Test method for damage qualification of reinforced concrete beams

Essais non destructifs — Contrôle par émission acoustique — Méthode d'essai pour la qualification des dommages des faisceaux de béton armé

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Foreword

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This document was prepared by Technical Committee ISO/TC 135, *Non-destructive testing*, Subcommittee SC 9, *Acoustic emission testing*.

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Introduction

Acoustic emission (AE) techniques are extensively developed in concrete engineering. Concrete structures have long been referred to as maintenance-free. Recently, however, it is realized that the concrete structures can deteriorate due to many factors. In particular, heavy traffic loads result in fatigue of the concrete structures.

In order to assess the fatigue of reinforced concrete beams, one criterion to qualify the damage levels is proposed on the basis of two ratios associated with the Kaiser effect.

New AE parameters of load ratio and calm ratio are defined for qualification of the damage. It is found that the damage qualified by the two ratios are in good agreement with actual damage of the beams. This suggests that the damage of the reinforced concrete structures in service as bridges, docks and buildings be quantitatively assessed, by simply applying cyclic loading and monitoring AE activity.

Non-destructive testing — Acoustic emission testing — Test method for damage qualification of reinforced concrete beams

1 Scope

This document specifies a test for damage qualification of reinforced concrete beams in services as bridges, docks and buildings.

2 Normative reference

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 12716, *Non-destructive testing — Acoustic emission inspection — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12716 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
AE activity
occurrence of AE hits or counts under stressed conditions in concrete

3.2
Kaiser effect
little *AE activity* (3.1) observed until the maximum load of the previous stage is surpassed when stresses are applied, removed and then reapplied to a material or a structure

3.3
Felicity ratio
ratio of the load at which emissions start to the previous maximum load when stresses are applied, removed and then reapplied to a material or a structure

Note 1 to entry: This shows the ratio of the degree of conformity of the *Kaiser effect* (3.2).

4 Requirement for the measuring system

For detection of AE signals, AE sensors shall be sensitive enough to detect AE signals generated in a concrete member, taking acoustic coupling into consideration. AE sensor shall be also robust enough against temperature change, moisture condition and mechanical vibrations in the environments. AE sensor shall be attached at proper locations to cover the target area.

In advance of the test, attenuation properties of the target structure shall be estimated, by employing the standard source. Based on this information, sensor location shall be determined in consideration with the attenuation properties.

The internal noise of the amplifier shall be inherently low and less than 20 μV (26 dB_{AE} for 0 dB_{AE} = 1 μV) as the peak voltage converted by input voltage. The amplifier shall be also robust enough against the environmental conditions and be protected properly.

The frequency range shall be determined prior to the measurement, taking into account the performance of AE sensor and the amplifiers. A suggested range in concrete is from around 10 kHz to 100 kHz, because such higher frequency components as over 1 MHz readily attenuate in concrete.

For signal analysis, AE parameters of AE count or AE hit shall be detected and processed. The measurement system shall be able to obtain time information along with AE data. In addition, such external parameters as load, strain and so forth are preferably recorded in the system, which can be equipped with enough memory to record the data measured. It is preferable that all the data recorded be analyzed digitally by computer.

5 Environmental noises

In advance of the AE measurement, the noise level shall be estimated. Then, counteract against external noises, wind, rain, sunshine and so forth shall be conducted to decrease the noise level as low as possible. In the case that the noises have similar frequency contents, amplitudes to AE signals or sources of the noises are unknown, characteristics of the noises shall be estimated prior to the measurement. Based on this result, separation of AE signals from the noises shall be achieved. In this respect, the use of filters is applicable after determining the proper frequency range. Normally, to eliminate mechanical noises due to vibrations, traffics and so forth, a high-pass filter over several kHz is useful. Elimination of electrical noises is made by a low-pass filter over around 100 kHz.

6 Test procedure

6.1 Basics

The period of the measurement shall be prescribed, depending on the conditions of a target structure or member, possibly in service. The sensitivity of the AE measurement system shall be checked routinely by employing the standard source. The variation within the channels shall be lower than ±3 dB_{AE}. The threshold level for counting shall be set as low as possible, depending on the level of the noises.

AE activity is evaluated from the number of AE counts or hits. The onset of AE activity is identified at the time when AE hits of peak amplitude with 5 dB_{AE} above the threshold are continuously observed under loading.

6.2 Failure modes of reinforced concrete beams and AE activity

Two failure modes are known. One is the bending-mode failure. In the beginning of loading, tensile cracks are nucleated at the bottom of a moment span due to bending moment. When the beam is either under-reinforced for bending or fully reinforced against diagonal shear failure, steel reinforcement in the axial direction yields and tensile cracks are further nucleated and then propagate upward. AE counts or hits in a beam of the bending-mode failure increases acceleratedly with the increase in loading. The other is called the shear-mode failure. In the case that the beam is over-reinforced or little reinforced against diagonal shear failure, final failure results from the sudden generation of diagonal shear cracks in the shear span without yielding of reinforcement.

AE counts or hits are observed at a constant rate because the reinforcement withstands until the final failure. Right before the final stage, diagonal shear cracks are observed without any precursors along with the rapid increase in AE counts or hits. Since AE activity in a damaged beam is of main concern to apply the recommended practice, these two failure modes should be taken into consideration in the case of AE monitoring.

With respect to AE activity in the reinforced concrete beam, a relation between crack-mouth opening displacement (CMOD) and the presence of the Kaiser effect is known. The Kaiser effect disappears in the case that either the values of CMOD due to bending-mode failure become wider than 0,1 mm and 0,2 mm, or the shear-mode failure is observed. It is noted that the values of CMOD over 0,1 mm approximately correspond to the serviceability limit of the reinforced concrete beam.

6.3 Load ratio and calm ratio

To quantify the Kaiser effect in AE monitoring, the Felicity ratio was proposed. Provided that the Kaiser effect is present, the ratio should be equal to 1,0. It was also reported that the ratio became lower than 1,0 due to the damage repeated in the reinforced concrete beams. In principle, the concrete structures undamaged are statically stable with high redundancy. Because the Kaiser effect is closely associated with structural stability, the ratio can become larger than 1,0 in a very sound structure. Due to damage accumulation, the ratio decreases to lower than 1,0, generating AE events even at lower loading levels than before. Thus, the ratio is a good indication of the damage accumulation and structural instability. Furthermore, AE activity during unloading is another indication of structural integrity. In the case that the structure is statically stable, AE activity is seldom observed in the unloading process whereas AE activity is observed even in the unloading process in case of unstable condition.

The ratios to estimate the Kaiser effect are defined, as follows:

a) ratio of load at the onset of AE activity to previous load:

$$L = \frac{L_o}{L_p}$$

where

L is the load ratio;

L_o is the load at the onset of AE activity in the subsequent loading;

L_p is the previous load;

b) ratio of cumulative AE activity during the unloading process to that of the last maximum loading cycle:

$$C = \frac{A_u}{A_t}$$

where

C is the calm ratio;

A_u is the number of cumulative AE activity under unloading;

A_t is the total AE activity during the whole cycle.

In practice, the damage assessment is proposed to classify the damage levels as prescribed in Figure 1.