CONCRETE RESEARCH LETTERS

www.crl.issres.net Vol. 2 (3) – Sep. 2011

Damage of Reinforced Concrete qualified by AE

M. Uchida[1c] T. Okamoto[2] and M. Ohtsu[3]
[1] *Taiheiyo Consultant, JAPAN*
[2] *College of Science and Engineering, Ritsumeikan University, JAPAN*
[3] *Graduate School of Science and Technology, Kumamoto University, JAPAN*

Abstract

In order to assess the damage levels of the structures, one criterion based on the Kaiser effect of acoustic emission (AE) is proposed. AE parameters of load ratio and calm ratio are defined for qualification of the damages. Accordingly, the feasibility of the damage qualification is experimentally examined by using reinforced concrete beams which are damaged under incremental-cyclic loading. It is found that the damages qualified by the two ratios are in good agreement with actual damages of the beams. This suggests that the damages of such reinforced concrete structures in service as bridges, docks and buildings are quantitatively assessed, by simply applying cyclic loading and monitoring AE activity.

Keywords: Reinforced concrete; Acoustic emission; Damage assessment; Load ratio; Calm ratio.

1. Introduction

Acoustic emission (AE) techniques have been investigated in concrete engineering for more than four decades [1-3]. Accordingly, AE techniques have been actively studied for health monitoring and diagnostic inspection. The standardization of AE testing procedure is in progress [4]. In order to assess the damage levels of reinforced concrete beams, one criterion to qualify the damage levels is proposed on the basis of two ratios associated with the Kaiser effect. A feasibility of this criterion is experimentally examined by testing reinforced concrete beams, which have been damaged under incremental cyclic loading [5].

2. AE parameters

In relation to the Kaiser effect, the ratio is defined as the ratio of load level, where AE events are newly observed in the subsequent loading cycle, to the previous load level. Provided that the Kaiser effect is present, the ratio should be equal to 1.0.

In principle, concrete structures undamaged are statically stable with high redundancy. Because the Kaiser effect is closely associated with structural stability, the ratio could become larger than 1.0 in a very sound structure. Due to damage accumulation, the ratio decreases lower

[c] Corresponding Author: Masakatsu Uchida
Email: Masakatsu_Uchida@grp.taiheiyo-cement.co.jp Telephone: +81 947323320 Fax: +81 947472038

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. Further, 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. On the basis of this finding, ratios to estimate the Kaiser effect are redefined, as follows;

(a) Ratio of **l**oad at the **o**nset of **A**E activity to previous loa**d**:

Load ratio = load at the onset of AE activity in the subsequent loading / the previous load.

(b) Ratio of **c**umulative **A**E activity during the un**l**oading process to that of whole **l**ast **m**aximum loading cycle:

Calm ratio = the number of cumulative AE activity during the unloading process/ total AE activity during the last whole loading cycle.

In the recommendation, the damage assessment is proposed to classify the damage levels as prescribed in Fig. 1. Thus, an application of the damage assessment is experimentally examined in reinforced concrete beams of the moderate sizes.

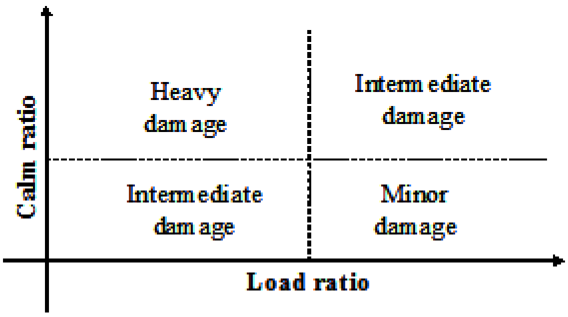

Figure 1. Classification of the damages by the two ratios [4].

3. Experiments

3.1. Test specimens and loading

Four kinds of five reinforced concrete beams were tested. Mixture proportion of concrete was selected as water = 166 kg, cement = 334 kg, sand = 802 kg, and gravel = 1021 kg for 1m^3 concrete. By using air-entraining admixture, air content was set up as 4.8% per volume and the slump measured was 14.5 cm. Compressive strength and modulus of elasticity after 28-day moisture cure were 31.1 MPa and 27.7 GPa, respectively.

One kind of the reinforced concrete beams were made without lateral reinforcement. To generate the bending-mode failure and the shear-mode in the same kind of specimens, the lateral reinforcement against diagonal shear cracks was not arranged and loading spans of the two were varied. The others were reinforced concrete beams with full lateral reinforcement. π-shaped displacement-meters were attached at the bottom to measure the crack-mouth opening displacements (CMOD) after initial cracks were observed. At incremental cyclic-loading, four incremental-loading cycles were selected. These are the 1st cycle up to initial cracking, the 2nd cycle up to the allowable maximum stress of reinforcement, the 3rd cycle up to reinforcement yielding and the final.

3.2. AE measurement

AE sensor of 150 kHz resonance was attached at the center of the top surface in the specimens. Frequency range was set from 10 kHz to 1 MHz, and the total amplification was 80 dB gain. For event-counting, a threshold level was set up at 50 dB. The measuring system was a MISTRAS-AE system (Physical Acoustics Corp.). Only AE hits, which corresponds to the number of AE events observed at one channel, were measured as one AE parameter for the Kaiser effect.

4. Results and discussion

The change of AE activities under cyclic loading is studied to qualify the damages based on the Kaiser effect. AE activity increases almost linearly in the loading processes. In process of the loading cycles, AE activity in the unloading process keeps more activated than before. From these data, first, a relation between the total number of AE hits and the maximum CMOD at each loading cycle was investigated. With the increase in the maximum CMOD, total number of AE hits proportionally increase with the relation to neither the channels of AE measurement nor the failure mode. Because the tensile cracks were further generated due to yielding of reinforcement, larger CMOD is observed in the beams of bending-mode failure. This suggests that the total number of AE hits during one loading cycle is closely related with the maximum CMOD, which can be evaluated by visual inspection.

At each loading stage, two of the load ratio and the calm ratio were determined. The data were arranged as a relationship between the calm ratio and the load ratio in Fig.1. Results are shown in Fig. 2. Based on the maximum CMOD observed in the beams, classification limits are set as 0.9 for the load ratio and 0.05 for the calm ratio. This is because the serviceability limit of the CMOD is less than 0. 1 mm in the Standard Specification, and the Kaiser effect was not observed in the case of the CMOD over 0.1 –0.2 mm. Into three zones of the minor damage, the intermediate, and the heavy, data plotted are reasonably classified in good agreement with the maximum CMODs. This implies that the damage levels of reinforced concrete beams can be qualified by the criterion based on the load ratio and the calm ratio, monitoring AE activity under cyclic loading or in the mobile-load test. It is noted that the limits classified for qualification should be determined in advance, based on preliminary tests for practical applications. In the beams studied here, 0.05 for the calm ratio and 0.9 for the load ratio are effective. Thus, a feasibility of the criterion is reasonably demonstrated. This implies that the proposed procedure is practically applicable to assess the damages of reinforced concrete bridges and associated structures.

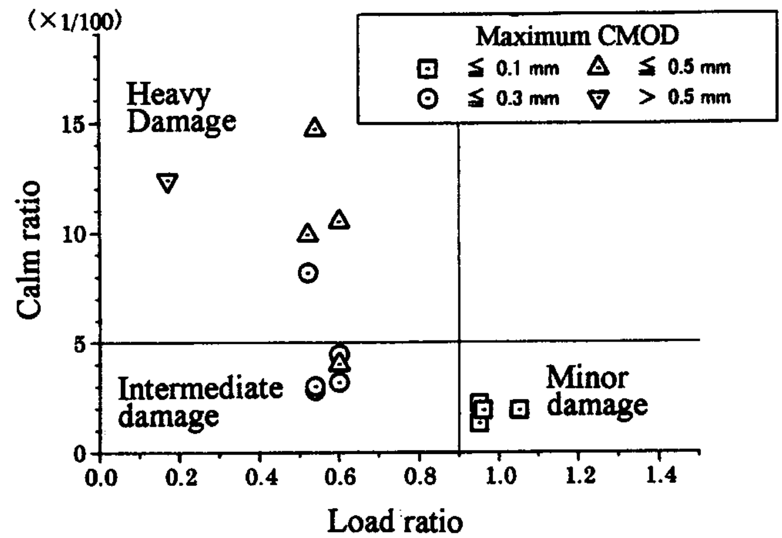

Figure 2. Classification of AE data obtained from beams.

5. Conclusion

The recommended practice by AE is proposed, prescribing one new criterion to assess the damage of the reinforced concrete bridges (beams) in service. Because a number of the concrete bridges are going to reach their service-life limit, an applicability of the criterion to qualifying the damage is investigated.

(1) In the deterioration process of the reinforced concrete beams with full lateral reinforcement, it is demonstrated the damage levels qualified by AE data shift from the minor to the heavy in process of incremental-cyclic loading. This clearly implies that the criterion proposed is applicable to assess the damage of reinforced concrete bridges and associated structures.

(2) It is noted that the present study is still limited to the laboratory research. Consequently, a field survey of real structures is planned to carry out the mobile-load test, and a procedure for routinely monitoring is under development. Further, an applicability of the two ratios to heavily damaged structures after many repeated loadings should be examined.

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