

# Research on Acoustic Emission Characteristics of Deterioration Reinforced Concrete Beams During Bending Load Failure

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## ABSTRACT

In order to investigate the acoustic emission (AE) characteristics of deteriorated reinforced concrete beams during bending load failure, three-point bending test was conducted on four reinforced concrete beams with varying degradation level simulated through freeze-thaw and corrosion cycle. AE parameters of reinforced concrete beams with different degradation level during bending load failure were analyzed, and the influence of deterioration level on AE parameters was revealed. The results show that the maximum cumulative ringing counts and AE energy decrease with degradation degree increasing. High-amplitude signal appears earlier comparing with that of non-deterioration beam. As deterioration degree continues to increase, the proportion of AE events with low rise-time continuously decrease, and proportion of AE events with high rise-time (rise time  $> 150\mu\text{s}$ ) exhibits a continuously increasing trend. Freeze-thaw and corrosion deterioration significantly reduce the strength and toughness of reinforced concrete beams, which causes significant changes in AE parameters. Therefore, the influence of deterioration should be considered in damage identification and early warning for in-service reinforced concrete bridge by using AE technology.

## INTRODUCTION

Reinforced concrete (RC) bridges are the most widely used type of bridge structure, accounting for over 90% [1]. During long-term service, RC bridges are inevitably subjected to vehicle load, environmental condition, and other external factors, which results in inevitable structural damage. These damages have a serious impact on structural safety and durability, even cause bridge collapse accidents [2]. According to statistics, cracking is the most common form of damage observed in in-service RC girder bridges, and it has the most significant impact on the degradation of structural performance. Timely and accurate identification of cracking in RC girder bridges is essential for ensuring operational safety and extending structural lifespan.

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Existing methods for identifying damage in reinforced concrete beams include structural dynamic response and non-destructive testing (NDT) techniques. Dynamic-based methods utilize global structural response data as damage indicators, which is insensitive to localized cracking in RC beams. NDT techniques are widely used in bridge damage identification due to their practicality and the advantage of non-destructive. Traditional NDT methods, such as ultrasonic testing, impact rebound, and surface wave techniques, are classified as active detection that require energy input [3]. However, the limited detection range and poor scalability make full-coverage inspection of large bridge structures difficult. AE technology, as a passive NDT method, detects transient elastic waves generated by crack formation within RC beams. These waves are captured by AE sensors and converted into electrical signals to evaluate structural damage [4]. AE can effectively detect micro-scale internal cracks and enables local, global, remote, and continuous monitoring without interrupting traffic. Therefore, AE technology has significant advantages in identifying structural cracks [5].

A series of studies have been conducted on the diagnosis of crack damage in concrete beam structures using AE technique. Thirumalaiselvi et al. collected AE signals of concrete beam during loading test and analyzed their characteristics to evaluate damage evolution by using unsupervised learning and support vector machine classification [6]. Prabhat et al. performed AE monitoring on concrete beams and found a strong correlation between AE parameters and failure modes such as shear, flexural, and combined failure [7-8]. Noorsuhada et al. analyzed AE parameters of RC beams under fatigue loading to classify and identify different cracking modes [9]. Radhika et al. investigated the fracture behavior of plain concrete under monotonic and fatigue loading through three-point bending tests [10]. AE parameters such as average frequency, rise angle, and energy were found to be effective in identifying damage initiation. Qin et al. studied the AE characteristics during shear damage in five simply supported RC beams to reveal the relationship between accumulation event and variables such as shear span ratio and aggregate size [11]. However, these studies ignored the influence of deterioration on AE characteristics of RC beams. In particular, the AE behavior during the bending failure of RC beams subjected to freeze-thaw corrosion remains unclear, which may lead to significant errors in crack damage identification under real service conditions. Therefore, it is crucial to analyze the difference of AE parameters with various deterioration degrees during the bending damage of RC beams to improve the accuracy of crack damage diagnosis in practical applications.

This study investigates the AE signals of reinforced concrete beams with varying degradation level simulated through freeze-thaw and corrosion cycle during bending failure. The difference of AE parameters such as ringing counts, amplitude, energy, and rise time are identified, and the influence of deterioration level on AE parameters is revealed. These will provide the foundation for crack damage identification and early warning of reinforced concrete bridges in complex service environments by use of AE techniques.

## **PRINCIPLE OF ACOUSTIC EMISSION**

AE refers to the phenomenon in which energy is released during the damage process of materials and structures, and propagates outward in the form of elastic waves. These

elastic waves are captured by AE sensors on the material surface and converted into electrical signals. AE parameters, such as ringing counts, energy, amplitude, and rise time, can be extracted, as illustrated in Figure 1. Specifically, amplitude is the peak value of waveform. Rise time is the time interval from the signal onset to its peak. Ringing count is the number of threshold crossings, and energy represents the area enclosed by the signal envelope and the threshold axis. These parameters capture the fundamental properties of AE signal and reflect the behavior of crack initiation and propagation.

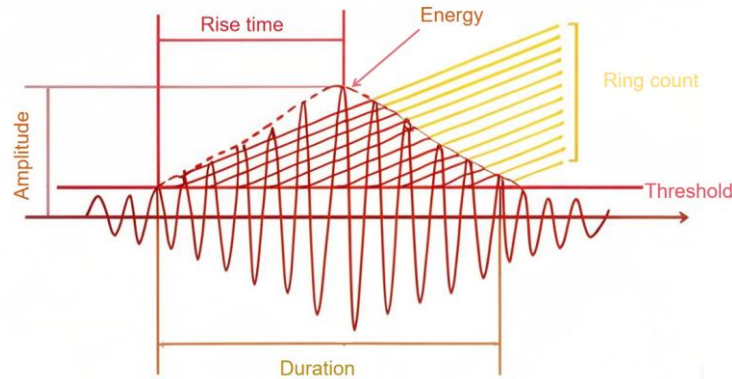


Figure 1. Schematic diagram of AE parameter

## EXPERIMENTAL OVERVIEW

### Test beam fabrication

The test beams are simply supported reinforced concrete beam with the dimensions of 1100 mm (length)×120 mm (width)×150 mm (height). Concrete strength grade is C40, and steel reinforcement is HRB400. The reinforcement layout is consisted of 2 $\Phi$ 12 tensile longitudinal bars, 2 $\Phi$ 8 racking bars, and  $\Phi$ 6 stirrups spaced at 100 mm intervals, as shown in Figure 2. A 28 day curing period is carried out for test beams after the pouring is completed.

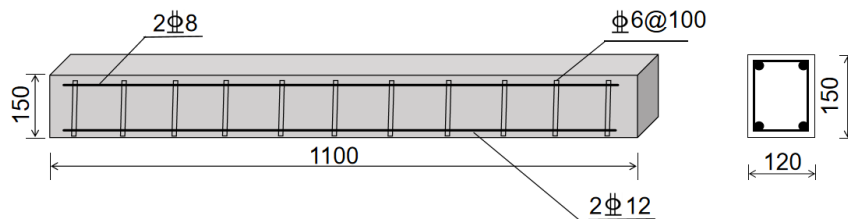


Figure 2. Schematic diagram of test beam (unit: mm)

### Test conditions

The test beams were initially immersed in a 5% NaCl solution for 72 hours to facilitate full infiltration of the electrolyte into concrete and promote formation of ionic

corrosion channels. A slow-freezing method was employed for freeze-thaw cycle. Firstly, the test beams were placed in a low-temperature freezer at temperature range of  $-20\pm 2^{\circ}\text{C}$  for 6 hours. Secondly, they were transferred to a 5%NaCl solution tank, where the solution was heated to  $20\pm 2^{\circ}\text{C}$  using a controlled heating device, and the beams were thawed for 4 hours. Finally, a DC power with a 12 V voltage and 0.6 A current was connected to accelerate corrosion for 4 hours. After completing above steps, one freeze-thaw corrosion cycle was completed. This cycle was repeated until each beam reached its designated number of cycles, as summarized in TABLE I.

TABLE I FREEZE-THAW CORROSION TEST CONDITIONS

Testing condition	Deterioration grade	Number of cycle
L1	Non-deterioration	0
L2	Mild deterioration	25
L3	Moderate deterioration	50
L4	Severe deterioration	75

### Loading and testing

The test beam was loaded using three-point bending with simply supported roller bearings placed at both ends with a spacing of 100cm. A hydraulic jack was positioned at top of the beam mid-span. A pressure transducer was installed between the jack and reaction frame steel crossbeam to control loading. Graded load was applied until the beams were destructed. The load level was 5kN, and loading rate was 5kN/min. After each level of loading completing, the load was held for 1 minute to observe and record the crack development. Four AE sensors were positioned on the side of test beam for capturing AE signal. Vaseline was used as the coupling agent between the sensors and the beam to minimize external noise. The system parameters were set as follows: sampling frequency 1 mHz, threshold value 40 dB, peak discrimination time (PDT)  $50\mu\text{s}$ , impact discrimination time (HDT)  $100\mu\text{s}$ , and impact locking time (HLT)  $300\mu\text{s}$ . The specific loading arrangement is shown in Figure 3.

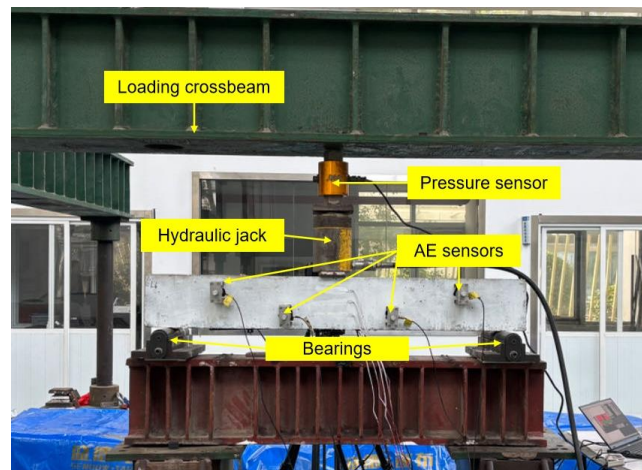


Figure 3. Test beam loading and testing arrangement

## TEST RESULTS ANALYSIS

### Ring count

Acoustic emission ringing count represents the total number of signals exceeding the threshold. It is commonly used to evaluate the activity level of acoustic emission signals. The cumulative ringing counts during loading process of test beams are shown in Figure 4. It can be observed that the destruction times for the L1, L2 and L3 test beams are similar, while the L4 test beam is destroyed at an earlier time. At the initial loading stage, cumulative ringing counts increase slowly. As the load increases, the cumulative ringing count growth rate continues to increase. Maximum cumulative ringing counts at the failure stage continuously decreases with the degradation degree of the test beam increasing. Comparing to the non-deterioration test beams, the maximum cumulative ringing counts of the L2, L3 and L4 test beams decreased by 35.82%, 50.83%, and 65.26%, respectively.

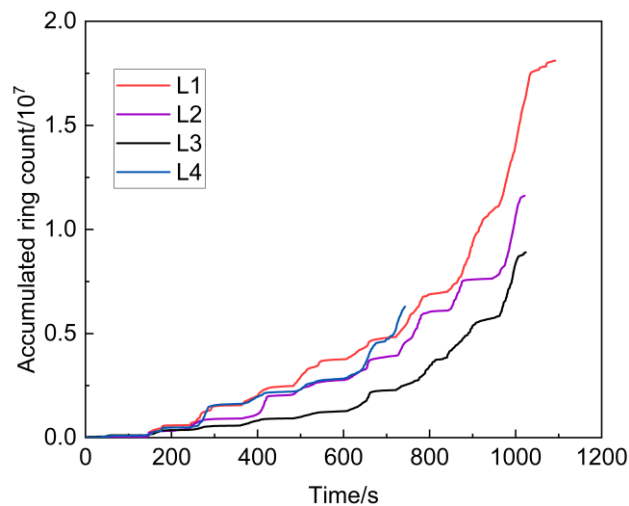


Figure 4. Comparison of AE cumulative ring counts

### Amplitude

Acoustic emission amplitude refers to the maximum instantaneous voltage recorded in the waveform of acoustic emission signal, which reflects the upper limit of stress wave intensity released by microscopic damage within material. The acoustic emission amplitude during the loading process of test beams is shown in Figure 5. High-amplitude signals are primarily concentrated in the loading stage, while low-amplitude signals dominate during the load-holding stage. When the loading time is less than 200s, the high-amplitude signals of L1 and L2 test beams with lower degree of deterioration are fewer. As the deterioration degree increases, the appearance time of high-amplitude signals of L3 and L4 test beams occurs earlier. This is caused by that freeze-thaw corrosion deterioration reduces the bearing capacity of test beams and leads to earlier structural damage.

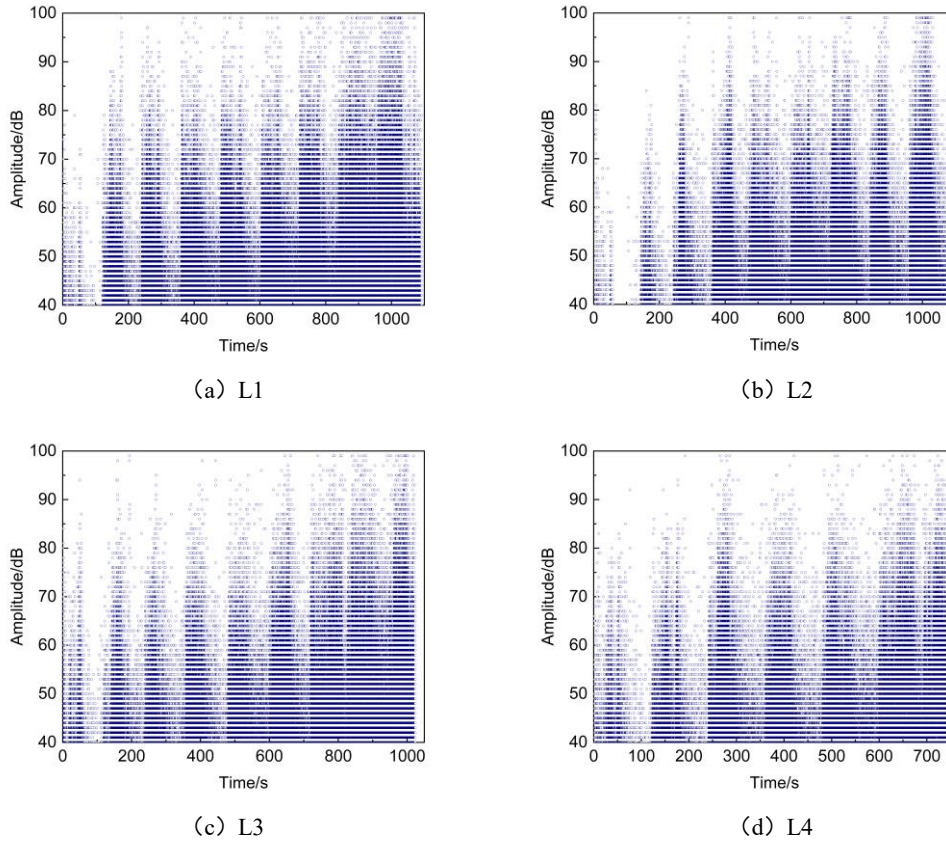


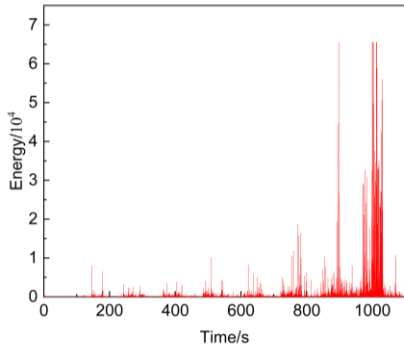
Figure 5. Comparison of acoustic emission amplitude

## Energy

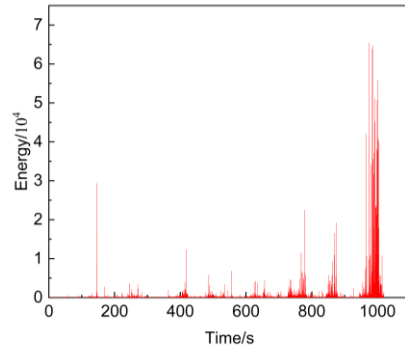
Acoustic emission energy is typically defined as the integral of acoustic emission signal envelope, which reflects the intensity of energy release from micro-damage events within the material. Acoustic emission energy during the loading process of test beams is shown in Figure 6. It can be seen that acoustic emission energy released during loading decreases as the degree of deterioration increases. Particularly near the destruction stage, the energy release of L3 and L4 test beams is significantly lower than that of L1 and L2 test beams.

## Rise time

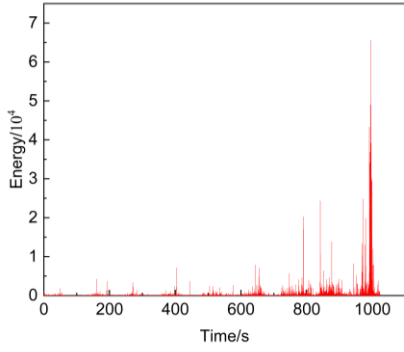
Rise time is the time interval required for acoustic emission waveform to reach its maximum amplitude from the initial excitation of the trigger threshold. It reflects the speed and abruptness of the energy release from the damage source. The longer the rise time, the slower the energy release. The statistics of acoustic emission events with different rise time during the loading process of test beams is shown in Figure 7. The percentages of acoustic emission events with rise time range of 0-30 $\mu$ s for L1, L2, L3, and L4 are 50.58%, 48.90%, 42.83%, and 40.26%, respectively. The percentage of acoustic emission events with low rise-time decreases as the degradation degree of test beams increases. The proportion of acoustic emission events with high rise-time (rise time > 150 $\mu$ s) exhibits a continuously increasing trend.



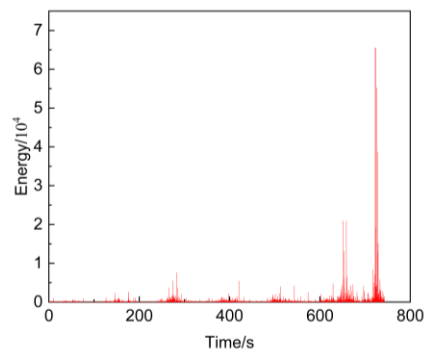
(a) L1



(b) L2

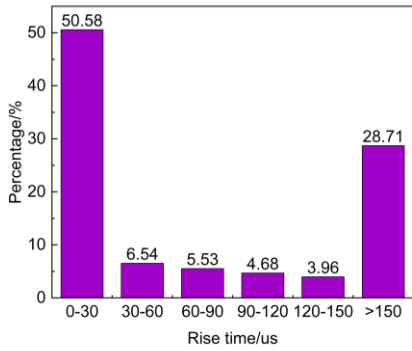


(c) L3

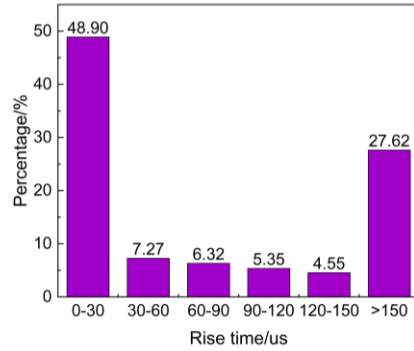


(d) L4

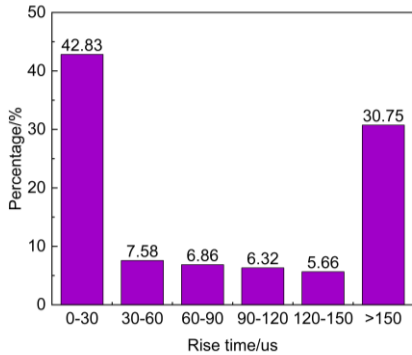
Figure 6. Comparison of acoustic emission energy



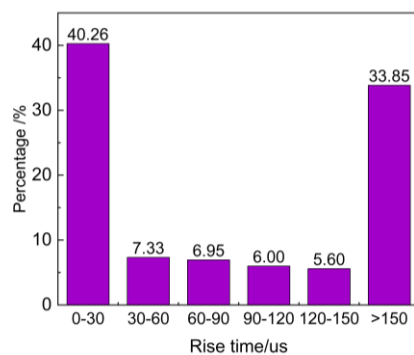
(a) L1



(b) L2



(c) L3



(d) L4

Figure 7. Comparison of acoustic emission rise time

## CONCLUSION

In this paper, the changes in AE characteristic parameters of ringing count, amplitude, energy, and rise time during three-point bending failure test of reinforced concrete beams after freeze-thaw corrosion deterioration are analyzed. The following conclusions have been obtained.

(1) Maximum AE cumulative ringing counts and energy continuously decrease as the degree of deterioration increasing. Comparing to the non-deterioration test beams, the maximum cumulative ringing counts of the deterioration beams decreased by 35.82%, 50.83%, and 65.26%, respectively.

(2) When the loading time is less than 200s, the high-amplitude signals of L1 and L2 test beams with lower degree of deterioration are fewer. As the deterioration degree increases, high-amplitude signals of L3 and L4 test beams occurs earlier.

(3) The percentage of acoustic emission events with low rise-time (0-30 $\mu$ s) decreases as the degradation degree of test beams increases. Conversely, the proportion of acoustic emission events with high rise-time (rise time > 150 $\mu$ s) exhibits a continuously increasing trend.

## ACKNOWLEDGMENTS

The authors express their appreciation for financial support of Natural Science Foundation of Jiangsu Province Basic Research Program (BK20220209); Jiangsu Province Youth Science and Technology Talent Support Project (JSTJ-2024-302).

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