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Original Research Article

Kaiser effect observation in reinforced concrete structures and its use for damage assessment

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ABSTRACT

Reinforced concrete (RC) beams of span 3 m were tested under incremental cyclic load at different loading rates and simultaneously during the fracture process in the RC beams acoustic emissions (AE) were recorded. An attempt has been made to study the Kaiser effect as a measure of damage in RC beams. It was observed that RC beams made with high strength concrete under incremental cyclic loading showed an obvious Kaiser effect before the failure load. The results may be useful to study the damage in concrete structures and provide a reference for the application of Kaiser effect in engineering practice.

1. Introduction

The damage of RC structures is related with initiation, nucleation, coalescence of microcraks, growth of microcracks which leads to fracture process and final failure in RC structures [1,2]. A number of highway bridges in India are made of reinforced concrete. In general, the RC bridges are usually designed and built for a service life of nearly 100 years. But it is generally felt that after 25–30 years, these RC bridges, owing to their usage and also due to adverse environmental effects, are found to undergo damage in different parts at various scales. Both localized and global damages have been occurring in RC structures quite frequently. In general, the damage commences in RC structures at the microlevel in the form of microcracks. It grows further with the increase of load (stress) leading to inelastic deformation, formation of macrocracks and fracture or fracture bands (tortuous bands) before the final failure occurs [1,2]. All these phenomena are responsible for the reduction in strength of RC structures [1,2]. Hence, the maintenance and safety during their long service-life is very important. Furthermore, the repair and rehabilitation has become an integral part in the maintenance of RC bridges and civil engineering structures which involves an extension of service life. It is known that non-destructive testing (NDT) methods are useful to assess the damage in the RC structures [3]. Among the available NDT techniques, the AE monitoring has been found to yield useful results [3–8]. AE monitoring is a unique, non-invasive and passive NDT technique. AE is a class of phenomena whereby transient elastic waves (covers audible frequencies and ultrasonic frequency range) are generated due to rapid release of strain energy from a localized source within a material [3–8]. In fact AE is a phenomenon of stress wave radiation (burst of high frequency elastic waves) caused by release of strained

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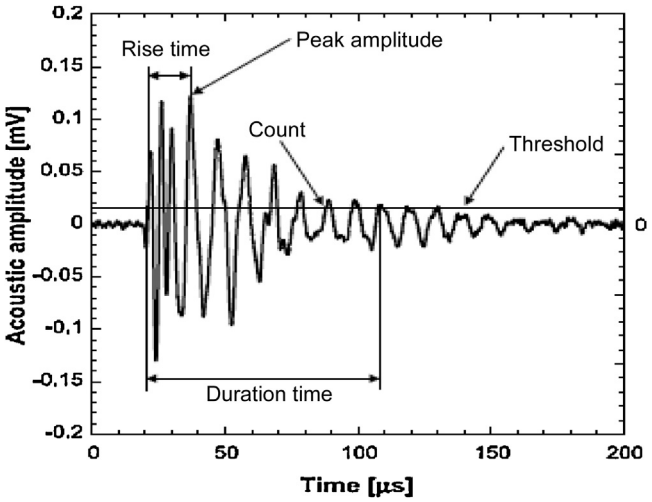

Fig. 1 – Schematic diagram of a typical AE signal and corresponding AE parameters.

energy released and dynamic reconstruction of material's structure that accompanies processes of deformation and fracture. In fact high stresses concentrate near cracks and other discontinuities in a material. Crack growth and propagation is accompanied by a rapid release of strain energy, a part of which is released in the form of stress waves. Stress waves are generated when the stress field changes and these stress waves are recorded using AE monitoring system in the form of AE signals [3–8]. Fig. 1 shows a typical AE signal and the corresponding AE parameters.

It was established that the acoustic emission analysis (AEA) has become a promising method to evaluate the damage in concrete structures [3–8]. Researchers and engineers use parametric and signal based AE techniques for the measurement and analysis of AE related to damage assessment. Several researchers contributed to development of AE techniques for application to concrete structures. Recently Vidya Sagar and Raghu Prasad reviewed the literature on parametric based AE techniques applied to concrete structures [9].

1.1. *Kaiser effect*

The absence of detectable AE until the previous maximum applied load has been exceeded is known as Kaiser effect. In other words, if a material is loaded, unloaded and then reloaded, AE will not be produced until the previous maximum load is exceeded. By using Kaiser effect phenomena the structural engineer can assess the maximum load experienced by the structure earlier. In fact the Kaiser effect is a measure of damage taken place in a material due to stress. This phenomenon has practical use to detect crack propagation under different loading conditions [3].

1.2. *RILEM TC-212 recommendations*

Over the last few years, attempts have been made successfully to study and qualify the damage in RC structures using parametric based AE techniques. Based on research activities on AE technique for crack detection and damage evaluation in concrete structures, the RILEM technical committee (TC 212-ACD) and NDIS-2421 were established with some guidelines and instructions [3,10,11].

1.3. *NDIS-2421 recommendations*

Usually AE monitoring is done to obtain qualitative results by observing the trends of AE parameters recorded during the experiment and the extent of damage is then evaluated. The Japanese Society for Non-Destructive Inspection (JNDI) has proposed a practice (NDIS: 2421) to monitor the damage in concrete structures [3,12].

1.4. *Moment tensor analysis of AE released during concrete fracture*

Quantitative procedures are proposed to identify an AE source. Profiting from the methods of geophysics, considerable results have been achieved with respect to determination of AE wave arrival times (picking), AE source localization and researchers proposed moment tensor analysis related to AE [3]. In a study related to simulation of crack propagation due to corrosion of reinforcing steel-bar, the moment tensor analysis was performed to identify the cracking mechanisms in concrete [3,13].

1.5. *Rate process analysis*

Ohtsu and Watanabe [14] have introduced the rate process analysis to evaluate quantitatively the changes of AE activity in reinforced concrete due to damage [3].

1.6. *AE amplitude distribution analysis*

In recent years, the application of AE parameters such as energy, count data and amplitude are used the utility of AE monitoring technique for the study of damage, fracture behaviour of engineering materials including concrete. The AE based *b*-value obtained from the amplitude distribution data of AE events (or hits) using the Gutenberg-Richter formula was utilized successfully for studying the damage, micro, macro-cracking in RC structures [3,15,16].

1.7. *AE energy analysis*

AE energy is an AE parameter useful to assess damage in concrete structures and researchers used to evaluate the damage in RC beams through laboratory investigations [17,18]. By utilizing the parameter 'relaxation ratio', Colombo et al. [18] concluded that there is a change in relaxation ratio at 45% of the ultimate failure load in concrete bridge beams [3]. AE monitoring experiments were performed successfully under incremental cyclic loading of RC beams with different percentage of reinforcement using AE energy parameter. By defining two ratios, namely, calm ratio and load ratio based on AE energy and Kaiser effect, the state of damage in RC beams was investigated [19,20]. A damage assessment chart was made using load ratio, calm ratio parameters and linking them to the crack mouth opening displacement (CMOD) [20]. The fracture