DAMAGE EVALUATION METHODS OF STRUCTURAL MEMBERS USING ACOUSTIC EMISSION (AE) TECHNIQUE

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by

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TEKNIK PENILAIAN KEROSAKAN STRUKTUR MENGGUNAKAN TEKNIK AKUSTIK EMISI

ABSTRAK

Akustik Emisi (AE) merupakan satu teknik penilaian tanpa musnah yang penting yang digunakan di dalam bidang kejuruteraan strukutur bagi kedua-dua kes pemantauan tempatan dan global. Teknik ini digunakan untuk menyiasat pembentukan proses kepatahan bagi konkrit bertetulang dan struktur keluli. Objektif utama dalam kajian adalah untuk membuat taksiran penilaian kerosakan bagi rasuk dan kerangka konkrit bertetulang dan juga rasuk keluli berkimpal, untuk menghasilkan kaedah komersial bagi penilaian tanpa musnah terhadap konkrit bertetulang dan struktur keluli. Beberapa kerangka satu tingkat konkrit bertetulang dan rasuk konkrit bertetulang dengan sambungan atau tiada sambungan tetulang membujur telah disediakan. Sebagai tambahan, beberapa specimen rasuk keluli berkimpal telah dihasilkan. Spesimen ini telah diuji di bawah kitar beban dan pemantauan menggunakan AE juga dijalankan serentak. Data daripada AE dianalisa menggunakan beberapa kaedah analisis AE seperti lokasi kerosakan, kaedah b-value, parameter kerosakan, kadaran santaian, ketenangan beban dan keamatan analisis. Keputusan bagi semua kaedah ini semasa dikenakan bebanan dan tidak dikenakan bebanan telah dibandingkan dengan kelakuan setiap jenis specimen tersebut. Semua keputusan menunjukkan bahawa AE boleh diklasifikasikan sebagai kaedah yang sesuai untuk menjangkakan baki hayat kebolehkhidmatan bagi konkrit bertetulang dan struktur keluli. Sebagai tambahan, daripada keputusan yang diperolehi dari analisis AE, beberapa carta baru telah dihasilkan.

DAMAGE EVALUATION METHODS OF STRUCTURE MEMBERS USING ACOUSTIC EMISSION (AE) TECHNIQUE

ABSTRACT

Acoustic emission (AE) is an important nondestructive evaluation (NDE) technique used in the field of structural engineering for both case local and global monitoring. This technique was employed to investigate the process of fracture formation in reinforced concrete and steel structures. In main objective of this research was damage evaluation assessment of reinforced concrete beam and frame as well as welded steel beam specimen, in order to provide a commercial method for the non-destructive evaluation of reinforced concrete and steel structures.A number of reinforced concrete (RC) one story frames and several RC beam specimens with continuous or non-continuous longitudinal rebar were prepared. In addition, several welded steel beam specimens were fabricated. These specimens were tested under loading cycle and were simultaneously monitored using AE technique. The AE test data was analyzed using the number of AE analysis method such as AE source location, b-value analysis method, and damage parameter, Relaxation ratio, Load ratio, Calm ratio and intensity analysis. The trend of these methods during loading and unloading was compared with behaviour of each type of specimens. The results showed that these methods were able to indicate the levels of damage. Also, the results showed that AE can be considered as a viable method to predict the remaining service life of reinforced concrete and steel structure. In addition, with respects to the results obtained from AE analysis, a number of new charts were proposed.

CHAPTER 1

INTRODUCTION

1.1 Background

Acoustic Emission (AE) is defined as the class of phenomena whereby transient elastic waves are generated by rapid released of energy from localized sources within a material or the transient waves so generated (ASTM, 2006).

The AE technique is one of the non-destructive evaluation (NDE) techniques that have been considered as the prime candidate for damage monitoring in loaded structures and structural health (Surgeon and Wevers, 1999). This technique is a useful testing tool for examination of the behaviour of materials deforming under stress real time (Nair and Cai, 2010). Also, AE technique can give valuable information damage within material service (Muravin, 2009). In addition, AE tests can be conducted during a slight enhancement of the load and under normal service conditions. Thus, it is extremely useful in testing (Grosse and Ohtsu, 2008).

Using of AE back to the middle of the twentieth century and started with publication of Kaiser's thesis and Kaiser Effect' was introduced (Matthews, 1983). In 1950, J. Kaiser reported investigation of different engineering materials about the effect of the absence of AE in materials under stress. This effect, bearing the name of Kaiser, is widely used in today's AE testing. Following researches, done in recent decades have revealed that Kaiser effect is a material specific and not all materials exhibit it, for example different composites. Also, in structures containing developing flaws it has been shown that the effect is not observed (Muravin, 2009).

Schofield (1963) followed the Kaiser works and published his work as entitled "Acoustic Emission". In 1960s, in parallel of different countries it was proposed to use AE method for practical non-destructive examination of various structures (Grosse and Ohtsu, 2008). Thus, in 1961 in USA, this technique was used for investigation of structural integrity of rocket motor cases fabricate for the United States Navy.

In 1963, AE was used for inspection of pressure vessels and several scientific research institutes started investigate AE and develop its application for non-destructive control of different structures and other, crack detection and material studies and mostly military related applications (Muravin, 2009). In 1967, the AE Working Group (AEWG) in USA and in 1980 Japanese Society for Non-destructive Inspection (JSNDI) in Japan were founded (Grosse and Ohtsu, 2008).

Nowadays, AE technique has been used in a variety of structures such as airframes (McBride et al., 1993), pipelines and pressure vessels (Roberts and Talebzadeh, 2003) and the field of Civil Engineering (Chang and Liu, 2003).

1.2 Problem statement

The determination of safe load carrying capacity of reinforced concrete and steel structures in real time is one of the important issues in field of Civil Engineering. The reinforcement concrete structures are subjected to different types of disasters such as chemical reactions, creep, corrosion and other disasters. Also, the steel structures are subjected to fatigue.

Furthermore, the safe load carrying capacity of these structures can come into question for a number of reasons including a change in use or occupancy, questions regarding details of construction, in some cases the use of newer materials and systems that may not be addressed in existing codes and standards (Ziehl and Pollock, 2012).

The reinforced concrete and steel structures require periodic inspections to ensure the structural safe service. A diagnostic inspection on the current state of the deterioration is necessary for maintenance. In addition, any decisions to repair or retrofit and reconstruct existing structures require real time data. Thus, there is a growing need to evaluate damage and predict remaining capacity life.

There are several non-destructive techniques for structure assessment but these testing methods for concrete and steel structures do not provide the full information about the severity of defects in real time. Therefore, there is a need for developing an effective non-destructive test method and corresponding evaluation criteria to evaluate their damage level and remaining load capacity before making such decision.

Extensive AE studies of concrete and steel structures have been reported and this method was proposed for monitoring of the concrete and steel structures. However, more study is needed to develop methods of analyzing the data recorded during the monitoring.

Commonly, previous works has been focused on local evaluation of welded steel plates that are non-civil structural systems and has not been used in Civil Engineering structures. In addition, no researches have been found to study on damage assessment of reinforced concrete beams using acoustic emission technique in different conditions (overlapped bar, shear and flexural failure). Also, the reinforced concrete frame has not been investigated using AE by researchers.

Hence, in this study, the topic is focusing on local evaluation of welded steel that are used in civil structural systems. In addition, in this study evaluation of reinforced concrete beam in different conditions and reinforced concrete frame will be investigated.

1.3 Objectives

The aims and objective of this research are

i. To investigate damage level of reinforcement concrete (RC) beam structures under cyclic loading using AE technique

ii. To investigate damage level of welded steel beam under cyclic loading using AE technique.

iii. To provide a suitable chart of AE analysis for evaluation of the steel welded steel beam and RC beam.

1.4 Scope of work

The research investigated the suitability of the acoustic emission technique to detect sources and intensity of damage in reinforced concrete and welded steel structures. This study focuses on reinforced concrete (RC) beam under cyclic loading in different condition such as with or without overlapped bar and, shear and flexural failure. Also, This study focuses on welded steel beam under cyclic loading in different welded zone. The research investigates absolute energy, AE amplitude and signal strength using such some method such as Calm and Relaxation ratio, b-value and Damage Parameter.

1.5 Thesis layout

This dissertation consists of seven chapters. Chapter 1 includes a brief of background of acoustic emission, problem statement, objective and scope of work. Chapter 2 includes a background of the application AE technique in steel structures and reinforcement concrete structures. Chapter 3 focuses on the theory of acoustic emission and a description of acoustic emission evaluation method. Chapter 4 describes the laboratory experiments of reinforced beam and frame specimens and the damage evaluation results achieved by each of the some method are discussed in detail. Chapter 5 describes the laboratory experiments of steel specimen and the damage evaluation results achieved by each of the some method are discussed in detail. Chapter 6 provides a summary of the work performed and conclusion along with a recommendation for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Acoustic emissions (AE) are essentially elastic stress waves, generated by a rapid release of energy from a localized source within a stressed material which can be detected by remote sensors (Fang and Berkovits, 1995). Figure 2.1 shows a diagram schematic represents the general working principle of an AE monitoring system. In this figure, the structure is under load, and an acoustic emission has been released from crack growth in the structure. The stress waves generated by crack growth propagate through the structure and their arrival is detected with a transducer. This transducer converts the mechanical disturbance at the surface of the structure into an electrical signal. This signal is either recorded in its entirety with the acoustic emission test system, or key features of the signal are recorded and the signal is then discarded (Eitzen and Wadley, 1984).

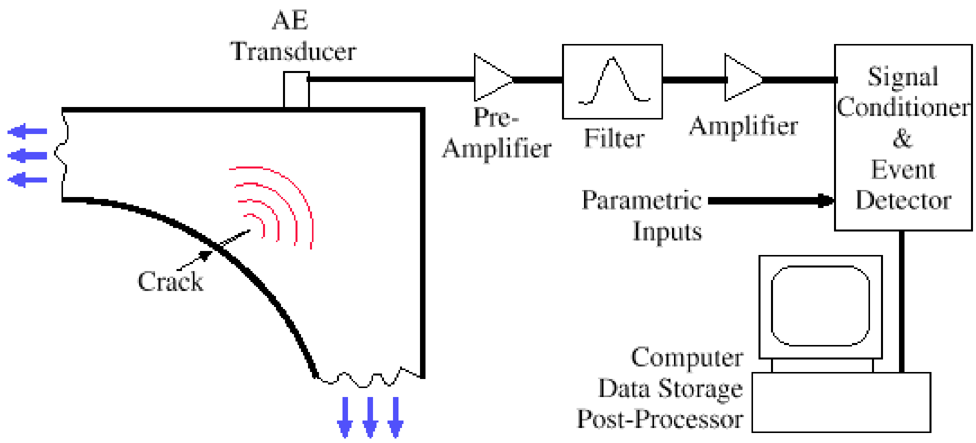

Figure 2.1 A schematic of acoustic emission (Huang et al., 1998).

Sudden movement at the source produces a stress wave, which radiates out into the structure and excites a sensitive sensor (Park et al., 2003). As the stress in the material is raised many of these emissions are generated. The signals from one or more sensors are amplified and measured to produce data for display and interpretation.

An AE monitoring system essentially requires two integral components. Firstly, a material deformation that becomes the source of AE. Secondly, a transducer that receives the stress waves that are generated from the AE source (Nair and Cai, 2010).

Load conditions that exist in structure have been known to cause materials like steel and concrete to emit AE energy in the form of elastic waves due to various material-relevant damage mechanisms (Nair, 2006). A developing flaw in these materials emits bursts of AE energy in the form of high frequency sound waves, which propagate within the material and are received by sensors (Nair and Cai, 2010).

In general, AE can be classified into primary and secondary emissions. Primary emissions generated from within the material of interest, while secondary emissions generated from external sources. AE event detection is closely related to the characteristics of stress waves, such source location algorithm criterion and wave mode, effects of multiple paths and attenuation (Holford and Lark, 2005).

Two types of AE monitoring can be adopted which are local and global. A local monitoring addresses a given specific area of damage while a global monitoring helps assess an entire structure's integrity (Carlos et al., 2000). The wide range for application of acoustic emission is between seismic event as the largest scale and the movements of small numbers of dislocation in material as the small scale (Pollock, 1989).The sources of AE are such as fracture, plastic deformation, crack face rubbing and phase changes in solids.

The main differences of AE techniques, compared to other non-destructive testing techniques are: (1) the energy is released from within the test object itself, (2) AE is capable of detecting the dynamic processes associated with the degradation of structures (Pollock, 1989).

The advantages of AE techniques, compared to other non-destructive testing techniques are: (1) damage processes in materials being tested can be observed during the entire load history, without any disturbance to the specimen, (2) AE tests can be conducted during a slight enhancement of the load and under normal service conditions. Thus, it is extremely useful in testing (Grosse and Ohtsu, 2008).

Also, the disadvantages of AE technique compared to other non-destructive testing techniques are: (1) a particular test is not perfectly reproducible due to the nature of the signal source, (2) due to the presence of background noise, real time separation requires several trial monitoring sessions and experienced personnel, (3) quantitative AE analyses are still difficult for applications (Grosse and Ohtsu, 2008 and Nair and Cai, 2010). In this study will be used the quantitative AE analyses method.

The primarily sources of AE are micro or macro-cracking, compression failure, yielding, fracture, de-bonding between materials, sliding and friction between interfaces. In metal, fracture development in form of crack propagation, plastic deformation development and fracturing of hard inclusions are primary sources of acoustic emission. Also, in concrete, fracture development in form of crack propagation, aggregate fracture and voids closure (Muravin, 2009).

The source of the AE energy is the elastic stress field in material and without stress, there is no emission. Thus, an AE monitoring is usually carried out during a controlled loading of structure.

The AE technique can detect not only crack growth and material deformation, but also, such processes as solidification, friction, impact, flow and phase transformation. Thus, AE technique is valuable for in-process weld monitoring, corrosion, etc.

AE technique is a powerful aid to materials testing and study of deformation and fracture and it gives an immediate indication of response and behaviour of a material under stress, intimately connected with strength, damage and failure. Because the AE response of a material depends on its microstructure and deformation mode, materials differ widely in their AE response. Brittleness and heterogeneity materials such as concrete and weld emitted AE signals with high level and ductile deformation mechanisms are associated with low emissivity (Adrian, 1987).

Approaches in recording and analyzing AE signals can be divided into two main types: (1) qualitative such as AE parameters, Hit or Count rates, Historic-severity, Load-Calm ratio and *b*-value analysis, (2) Quantitative such as AE event forming, source parameters and moment tensor inversion. Qualitative methods are the statistical analysis of AE parameters and do not relate observations with physical parameters. In addition, these methods can be performed with as few as one sensor and readily available and implemented in commercial AE systems relative measure, only comparable if exact same conditions depend on selected acquisition and threshold criteria. Quantitative methods are relates observations with physical parameters and require a network of sensors. In addition, these methods require data with high signal-to-noise ratio (Schumacher et al. 2011).

2.2 Basic AE parameters

The electrical signal identified as an AE signal is generated by fracture phenomena. Thus, characteristics of AE parameters have been evaluated to infer fracture or physical phenomena. Commonly, in AE testing a number of parameters are recorded from the signals, or sensor "hits". From these parameters, the condition of the specimen is determined. Figure 2.2 shows a schematic diagram a conventional AE signal features. With respect to this figure, basic AE parameters that widely used are explained as the following:

Threshold: A voltage level on an electronic compactor such that signals with amplitudes larger than this level will be recognized.

Amplitude: The peak voltage of the largest excursion attained by the signal waveform from an emission event. Amplitudes are expressed on a decibel scale. Amplitude is measured in decibels which is related to volts and is formulated;

$$A=20 \text{ Log } (V/1000) \tag{2.1}$$

Peak Amplitude: Maximum signal amplitude within the duration of the signal.

Duration: the time between AE signal state and AE signal end.

AE Count: The number of times the signal amplitude exceeds the pre-set reference threshold.

Energy: energy is relative value proportional to the true energy of the source event.

Absolute Energy: This is a true energy measure of an AE hit whose units are measured in attoJoule (aJ). Absolute Energy is derived from the integral of the squared voltage signal divided by the reference resistance over the duration of the AE waveform packet.

Event: A single AE source produces a transient mechanical wave that propagates in all directions in a medium. The AE wave is detected in the form of hits on one or more channels. An event therefore, is the group of AE hits that was received from a single source.

Hit: A hit is the term used to indicate that a given AE channel has detected and processed an AE transient.

Signal Strength: Area under the envelope of the linear voltage time signal from the sensor. The signal strength will normally include the absolute area of both the positive and negative envelopes.

Rise-time: The interval between the first threshold crossing and the maximum amplitude of the signal.

Signal Features: Measurable characteristic of AE signal, such as amplitude, AE energy, duration, counts, rise-time, that can be stored as a part of AE hit description.

Figure 2.2 shows a conventional AE signal features.

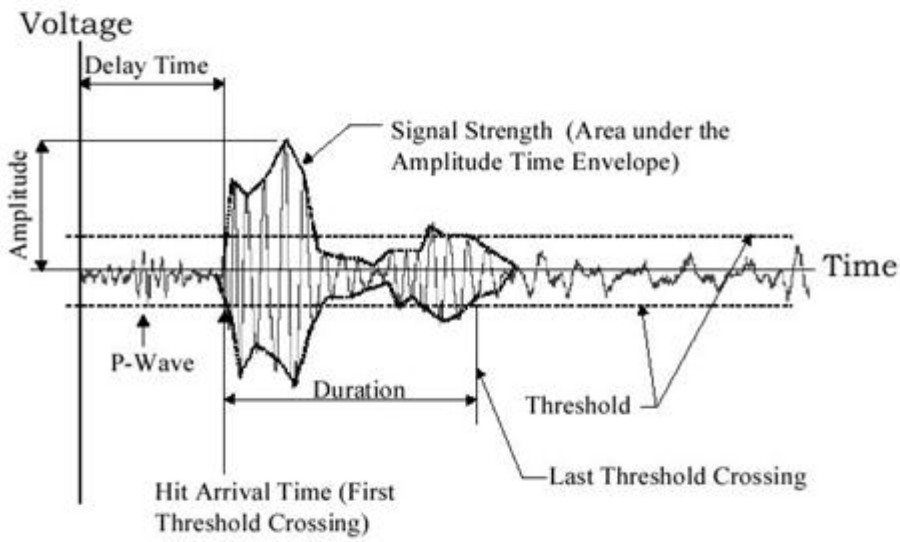

Figure 2.2 Features of acoustic emission signal (Tinkey et al., 2002)

2.3 Application of AE technique in civil structures

The main goal of AE monitoring in structures is to detect, source, and assess the intensity of damage (Holford and Lark, 2005). AE method is a passive non-destructive technique that can be applicable in structural health monitoring (Wang et al., 2011). AE technique has been used for source location and damage intensity predictions in field of Civil Engineering both steel and concrete structures. In addition, this technique has been used in local and global evaluation of steel and concrete structures include some different of local and global monitoring. Local monitoring is defined as a source location examination of a known flaw. Global monitoring is defined as large scale monitoring of a structure when no specific flaws are known (Anastasopoulos et al., 2009).

2.3.1 Application of AE technique in local evaluation of concrete structures

The primary sources of acoustic emission in concrete structures are numerous and include cracking of the concrete (crack extension), rubbing of crack surfaces during crack closure, de-bonding of the reinforcing steel from the surrounding concrete, and localized cracking in the vicinity of the reinforcement due to doweling action (Li et al., 2011). AE technique has been used for source location and damage intensity predictions in field of concrete structure.

Several researchers have the evaluation of plain concrete using AE technique (Ouyang et al., 1991). They studied AE during the application of compressive load on plan concrete and this has been known as one of the first studies on the „Kaiser effect" in engineering materials and Kaiser effect was observed up to a load of around 75% of the failure load (Grosse and Ohtsu, 2008). On the basis of the AE activities in concrete observed, it was concluded that when both Poisson"s ratio and axial strain are increased, the wave velocity decreases (Hermite, 1960).

Robinson (1968) studied the relationship between the fracture process and volumetric change of concrete under un-axial compressive loading using AE method. The AE events even during the unloading process were observed. In addition, generation of AE was closely related to the volume change in a specimen.

Chen and Liu (2007) evaluated the effects of maximum aggregate size on fracture behaviour of performance concrete using acoustic emission. The results showed that with the increasing of maximum aggregate size, the fracture energy of concrete increased.

AE technique has been used in evaluation corrosion phenomena in reinforced concrete structures (Sathiyanarayanan et al. 2006). Li and Xi (1995) investigated the concrete cracking and rebar corrosion using AE technique. They stated that micro cracks generate a large number of small amplitude and a large number of high amplitude is generated by macro cracks. Different type of acoustic emission signals with varying frequency ranges and amplitudes are produced from different fracture mode. Shear cracks create small amplitude while tensile cracks create larger amplitude signals. It is found that tensile cracks generated mainly in the bending test, in constant, shear cracks occurs dominantly in the diagonal-shear failure. It is might be occurred due to the difference of failure process.

The reinforced concrete (RC) beam specimen subject to corrosion of steel was monitored by Yoon et al. (2000). The RC specimen were tested under cyclic loading. They observed that AE counts decrease with the increase in degree of corrosion. Also, the level of damage in RC beam due to corrosion using AE technique has been known. The loss of bar cross section was taken as the rate determining parameter.

Ramadan et al. (2008) studied the stress corrosion cracking of high strength steel used in pre-stressed concrete structures using AE technique. This study showed promising results for a potential use in situ of AE for real-time health monitoring of steel cables used in pre-stressed concrete structures.

Several researchers have been studied RC structure using basic AE parameters such as AE Count, AE Hits and AE amplitude such as Ohtsu et al. (2002), Kan et al. (2008) and Aggelis et al. (2009). Ohtsu et al. (2002) investigated the RC beam using AE technique. They observed that AE Count and Hits rate increases exponentially in an under RC beam sliding between reinforcement and concrete. In contrast, in an over-reinforced beam, AE count rate remained at a constant rate until final failure.

Researcher considered AE amplitude as one of the parameter to evaluate cracks in RC beams. They have been found that shear and flexural cracking in concrete had larger amplitudes and duration than micro cracking phases of damage (Yoon et al., 2000).

Acoustic emission measurement used to assess the behaviour of concrete elements subject to flexural loading. Study of various AE parameters such as AE count and AE energy showed that the AE parameter is an away to distinguish between flexure and sheer fracture modes that occur during loading (Prewo et al., 1986). Thus, the AE parameter can be as indicators to predict fracture behaviour of concrete structures in health monitoring process.

Otsuka and Date (2000) have made use of AE energy to determine the quantum of AE energy released across the width of compact tension specimens and to arrive at the size of fracture process zone. They have concluded that zone over which AE energy is released is about 95% can be regarded as the fracture process zone.

Sagaidak and Elizarov (2007) studied fracture and deformation processes of concrete members using AE technique.The results showed that AE parameters of energy and duration with cracking process are correlated. In addition, frequency characteristics of AE events could depend on the cracks size and deformations. The cracks growth results in decreasing the dominated frequency of AE frequency spectra. Also, using occurrence AE events, initiation and growth of cracks in concrete structures could be estimated.

Muralidhara et al. (2010) studied fracture process zone size and true fracture energy of concrete using acoustic emission. They stated that with respect to time, a steep increase in the cumulative AE energy of the events and the formation of fracture process zone are correlated. Thus, the fracture process zone size depends on the number of events and the total AE energy recorded.

The b-value is a significant method for analysis of AE signals. This method has been used for structure damage evaluation by several researchers such as Dunn et al. (1984), Shiotani et al. (2001), Colombo et al. (2003), Kurz et al. (2006), Ko and Yu (2009), Proverbio (2011), Carpinteri et al. (2011), Schumacher et al. (2011), Li and Coa (2012) and Farhidzadeh et al. (2013).

Colombo et al. (2003) carried out a laboratory test on a reinforced concrete beam and evaluated AE data using b-value analysis method. The results showed a good relationship is between b-value and the micro-cracking and macro-cracking appearing during the test. The macro-cracks have formed is suggested by the Minimum b-value trend whilst micro-crack growth is implied maximum b-value trend. In addition, the results showed b-values decreased as the appearing of cracks and are mainly between 0.5 and 2. They found that A high b-value arises due to a large number of small AE events representing new crack formation and slow crack growth, whereas a low b-value indicates faster or unstable crack growth accompanied by relatively high amplitude AE in large numbers.

Two full-scale reinforced concrete deck girder bridges under realistic service and overloading condition using AE technique were investigated by Schumacher et al. (2011). They suggested Minimum b-value as a new method for evaluation of AE data. The results showed that minimum b-values decreased with higher applied forces even. In addition, the results showed that such overloading produce b-values well below 1.0, most likely even below 0.5.

The relaxation analysis that are derived of the AE activity during loading and unloading push has been used by a few researchers to evaluate structural damage such as Colombo et al. (2005) and Liu and Ziehl (2009), Proverbio (2011), Vidya Saga et al. (2012) and Goszczyńska et al. (2012).

Colombo et al. (2005) investigated RC bridge beams with different design and loading configurations using relaxation ratio analysis method. The results showed that relaxation ratio is greater than one when approximately 45% of the ultimate load was applied.

The calm and load ratio analysis that are similar to the relaxation analysis has been used by several researchers for evaluation of concrete structure such as Ohtsu et al. (2002), Luo et al. (2004), Colombo et al. (2005), Shiotani et al. (2007), Lovejoy, (2008) , Liu and Ziehl (2009), Lacidogna et al. (2010), Proverbio (2011), Vidya Saga et al. (2012) and Goszczyńska et al. (2012) .

A load ratio more than 1 is a criterion of a structure in good condition, whilst a value less than 1 suggests the presence of damage. A load ratio more than 1 is a criterion of a structure in good condition, whilst a value less than 1 suggests the presence of damage (Kaiser, 1953).

Lovejoy (2008) investigated a large number of full-scale laboratory test beams similar to highway bridge structure under a cyclic load using AE technique. The AE data recorded using the Felicity and Calm ratios were analyzed. The results showed the Calm ratio reasonably tracks accumulated structural damage in shear dominant loadings. Also, he found that by using diagonal tension crack mouth widths is a reasonable and easily applied method of estimating accumulated structural damage in the test beams. In addition, a new threshold on the Load and Calm ratios specific to this class of structure and loading was suggested.

A number of reinforced concrete beams using Calm and Load ratio analysis method were evaluated by Liu and Ziehl (2009). The results showed that the Load ratio with increasing load decreased and the Calm ratio with increasing load increased.

The Intensity analysis (IA) is an evaluation method of the deterioration of a structure using two parameters called Severity and Historic. Intensity analysis has been used for evaluation of RC structure and RC structure retrofitted using Fiber Reinforced Plastic (FRP) such as by several researchers such as Yuyama and Ohtsu, (2000), Kalny et al. (2003), Degala et al. (2009), Soulioti et al. (2009) , Proverbio (2011) and Goszczyńska et al. (2012).

The damage identification in post-tensioned concrete structures under cyclic load was performed using IA method. Intensity chart evidenced a higher damage level in last cyclic loading (Proverbio et al., 2009).

Characterization of fracture mechanisms in RC beams reinforced with reinforcing bars and Fiber Plastic Sheets using moment tensor analysis was investigated by Yuyama and Ohtsu (2000). They reported that the breakdown of the Kaiser Effect take placed once shear cracking started to set in and high AE activity in unloading phases indicate serious damage.

Kalny et al. (2003) evaluated the change in AE signature exhibited in reinforced concrete specimen under static loading conditions before and after repair using FRP. They concluded that AE activity was clearly distinguishable prior to repair, and that pre-existing damage detection was possible by observing AE activity trends.

Degala et al. (2009) studied the concrete slab specimens strengthened with Glass Fibre-reinforced plastic (GFRP) strips using AE method. The data obtained was evaluated using Intensity Analysis method. The results presented showed that Intensity Analysis method can be used in-situ for real-time health monitoring of structural systems of reinforced concrete retrofitted with Carbon Fibre-reinforced plastic (CFRP).

The behaviour of steel fibre RC under bending was evaluated by Soulioti et al. (2009). The steel fibres of varying content were used and the influence of steel fibre content on fracture behaviour and AE were investigated. The results showed that the AE activity is directly proportional to the fibre content in concrete.

Based from the literature review of the application of AE technique in local evacuation of concrete structures, all researchers have done their study in monitoring the deterioration of the reinforced concrete by Acoustic emission. Many methods have been used for local evaluation of reinforced concrete structures such as b-value, Relaxation ratio, calm and Load ratio and intensity analysis. No researches have been found on damage assessment of reinforced concrete beams using acoustic emission technique in different conditions which had an overlapped bar, shear and flexural failure. In addition, some method analysis such as b-value and Relaxation ratio are needed to investigate further. Because, there is no any chart for b-value and Relaxation ratio for damage level assessment of reinforced concrete structure .

2.3.2 Application of AE technique in global monitoring of concrete structures

AE technique indeed is a passive non-destructive technique that can be apply to the global evaluation (Proverbio, 2011). The majority of application AE technique in global monitoring of concrete structures have been focused on RC bridge (Nair and Cai, 2010).

Ohtsu et al. (2002) monitored an aged dock under mobile loading using AE technique. Three levels of loading was applied using three cases bearing capacity of truck which are empty truck, half loaded and full load. In first case, during loading and unloading phase, fewer AE hits were observed. In the second case, during loading phase and during unloading phase, Kaiser Effect was observed. In the third case, during loading and unloading phases, no Kaiser effect was observed. The Kaiser effect was not observed, as AE activities were quite high during both loading and unloading processes. This result implied that the Kaiser effect is applicable to qualify the damage levels of the concrete structures in service, by applying mobile loads (Ohtsu et al., 2002).

Vogel et al. (2006) reported a monitoring work of pre-stressed concrete bridge. Pre-stressed concrete structures are known to have almost no cracks at their initial phase of service life; thus, they suggested that AE might prove more beneficial in monitoring new cracks that may develop during their service life. The potential of AE testing as a global monitoring for examination of large volumes using a limited number of sensors was confirmed.

A number bridge structures reinforcement corrosion under traffic load were evaluated by Korenska et al. (2006). The experimental test investigated acoustic emission method to evaluate deterioration of pre-stressed reinforced concrete girders during flexural tests under loadings. The results provide that AE technique was very sensitive to detect the initiation of micro cracks generated near the interface between and concrete and the pre-stressed reinforcement.

The suitability of acoustic emission to monitor large concrete structure was evaluated using the values of quantification indices like the Calm ratio and b-value by Shiotani et al. (2007).This shows the potential of AE testing as a global monitoring of RC structures.

Schumacher et al. (2011) evaluated reinforced concrete highway bridges under realistic service conditions using AE technique. The data recorded using Minimum b-value analysis method was investigated. The b-value analysis appears especially well suited for performance in a real-time structural health monitoring because it is computationally inexpensive and, theoretically, only one sensor is needed to obtain a result. The results showed that minimum b-values decreased with higher applied forces even. Therefore it could be said that Minimum b-value analysis has the potential to estimate the load levels on operating RC bridge girders.

Based from the literature review from application of AE technique in global evaluation of concrete structures, all researchers have done their study in monitoring the deterioration of the reinforced concrete beam and no researches have been found that focused on evaluation of frame structure.

2.3.3 Application of AE technique in local evaluation of steel structures

One of primary sources of acoustic emission in steel structures is cracking, in particular fatigue cracking. Numerous laboratory studies such as Morton et al. (1973), Holford (1994), Hamstad and McColskey (1999), Roberts and Talebzadeh (2003), Na et al. (2006), Martínez et al. (2010) and Mukhopadhyay et al.(2012) have been conducted to demonstrate the ability of AE to detect cracks prematurely. They have been focused on monitoring fatigue crack development and its correlation with AE activity in steel members (Nair and Cai, 2010).

Harris and Dunegan (1974) indicated a model to explain the relationship between AE count rate and stress severity range by relating the energy released during crack extension to AE counts. Lindley et al. (1978) reported the first detailed investigation of the crack closure phenomena with respect to the detection of AE. This study was to improve the Harris and Dunegan model and considered the contributions to AE counts from plastic deformation and fracture events within the plastic zone ahead of the crack tip. The results indicated that data points in the curve of AE count rate versus stress intensity range are more scattered than those in the crack growth rate curve.

Shi et al. (2000) on the fatigue crack of cylindrical stainless steel specimens under torsion load using AE technique. The results indicated that the uniform growth, growth of micro-cracks and coalescence of micro- cracks into localized during the fatigue specimens are recognizable using AE technique.

AE technique has been used for evaluation of fatigue cracks in welded steel by researches. Roberts and Talebzadeh (2003) investigated the fatigue crack propagation in steel, welded steel compact tension and T-section girder specimens using AE technique. A good correlation between acoustic emission count rate and crack propagation obtained. The test results indicated that the prediction the remaining fatigue life of a structure is possible.

Na et al. (2006) studied the fracture behaviour of SA-516 steel welds. The base metal, post–weld head treatment and welded specimens of SA-516 steel during fracture testing were evaluated using AE technique. The results showed that micro-cracks at load between the yield and midpoint to maximum load were intuited and AE signals are generated at same loading range.

Fatigue tests were performed to detect AE signals from fatigue cracks using compact tension specimens made of ASTM A572G50 (1997) by Yu et al., (2011). The results showed that AE Absolute Energy rate might be more suitable than count rate in fatigue prediction for the material.

Based on the literature review from the application of AE technique in local evaluation of steel structures, commonly, previous works has been focused on local evaluation of welded steel that are non-civil structural systems and has not been used in civil engineering structures. In addition, no studies have been found on damage assessment of steel using AE analysis method such as intensity analysis or cumulative Hits and Count.

2.3.4 Application of AE technique in global monitoring of steel structures

Generally, in field of global monitoring of steel structures, AE technique has been used for global monitoring of bridges (Turek et al., 2013). Perhaps the first to apply AE for testing bridges was carried out by Pollock and Smith in the 1970s. They monitored a portable military bridge subjected to proof testing, and amplitude distribution analysis and source location results were reported (Nair and Cai, 2010).

During 1980 –1982, a bridge on I-471 using AE was monitored by Kentucky Transportation Research Centre. They reported effects of traffic and rainfall as sources of emission noise. The source classification for filtering out noise and for discriminating between different damage related events, such as brittle fracture and fatigue, were demonstrated (Miller and McIntire, 1987).

Prine and Hopwood (1983) considered an AE weld monitoring system for both fabrication and in service evaluations of bridge components. They had found that emission signals from bridges contain information on traffic volume, vehicle speed, weight, transducer characteristics and on structural details and transducer characteristics.

Kalicka (2010) investigated a 3D full scale model of a steel bridge joint using AE technique and signal analysis including waveform pattern identification has been completed. He has been discovered various phenomena with regarding the behaviour of acoustic signals transferred through different structural elements. For example, were fatigue cracks, friction and corrosion.

Two large steel bridges in conjunction region and suspected crack location under normal service loads using AE were monitored by Kosnik et al. (2011). The results showed that acoustic emission testing is well suited to the problem of characterizing cracks in steel bridge detail as actively growing or extinguished.

Yu et al. (2011) carried out studies on fatigue crack growth in steel bridge components using AE. They had found that the AE Absolute Energy rate may be more suitable than count rate in fatigue life prediction for the material. A summary of literature review are presented in Table 2.1.

Table 2.1 A summary of literature review

year	Author(s)	Output
2003	Colombo et al.	Colombo et al. (2003) carried out a laboratory test on a reinforced concrete beam and evaluated AE data using b-value analysis method. The results showed a good relationship is between b-value and the micro-cracking and macro-cracking appearing during the test.
2011	Schumacher et al	Two full-scale reinforced concrete deck girder bridges under realistic service and overloading condition using AE technique were investigated by Schumacher et al. (2011). They suggested minimum b-value as a new method for evaluation of AE data. The results showed that minimum b-values decreased with higher applied forces even.
2005	Colombo et al.	Colombo et al. (2005) investigated RC bridge beams with different design and loading configurations using relaxation ratio analysis method. The results showed that relaxation ratio is greater than one when approximately 45% of the ultimate load was applied.
2009	Liu and Ziehl	A number of reinforcement concrete beams using Calm and Load ratio were evaluated by Liu and Ziehl (2009). The results showed that the Load ratio with increasing load decreased and the Calm ratio with increasing load increased.
2009	Proverbio et al.	The damage identification in post-tensioned concrete structures under cyclic load was performed using IA method. Intensity chart evidenced a higher damage level in last loading cycle (Proverbio et al., 2009).
2003	Roberts and Talebzadeh	Roberts and Talebzadeh (2003) investigated the fatigue crack propagation in steel, welded steel compact tension using AE technique. A good correlation between acoustic emission count rate and crack propagation obtained.
2006	Na et al.	Na et al. (2006) studied the fracture behaviour of steel welds. The results showed that micro-cracks at load between the yield and midpoint to maximum load were intuited and AE signals are generated at same loading range.
2011	Yu et al.	Fatigue tests were performed to detect AE signals from fatigue cracks using compact tension specimens by Yu et al., (2011). The results showed that AE Absolute Energy rate might be more suitable than count rate in fatigue prediction for the material.