UNIVERSITI SAINS MALAYSIA

LAPORAN AKHIR PROJEK PENYELIDIKAN JANGKA *PENDEK*

FINAL REPORT OF SHORT TERM RESEARCH PROJECT

Sila kemukakan laporan akhir ini melalui Jawatankuasa Penyelidikan di Pusat Pengajian dan Dekan/Pengarah/Ketua Jabatan kepada Pejabat Pelantar Penyelidikan

RECEIVED 18 SEP 2012 UNIVERSITI SAINS MALAYSIA

1. Nama Ketua Penyelidik: Dr. Norazura Mohammad Bunnori
Name of Research Leader

☐ Profesor Madya/ *Assoc. Prof.* ■ Dr./ *Dr.* ☐ Encik/Puan/Cik *Mr/Mrs/Ms*

2. Pusat Tanggungjawab (PTJ):
School/Department

PP Kejuruteraan Awam (PPKA)

3. Nama Penyelidik Bersama:
Name of Co-Researcher

PM. Dr. Megat Azmi Megat Johari & Dr. Shahid Kabir

4. Tajuk Projek:
Title of Project

Acoustic Emission Technique (AE) for The Damage Assessment of Structures.

5. Ringkasan Penilaian/*Summary of Assessment*:

	Tidak Mencukupi *Inadequate* 1	2	Boleh Diterima *Acceptable* 3	Sangat Baik *Very Good* 4	5
i) **Pencapaian objektif projek:** *Achievement of project objectives*	☐	☐	☐	☐	■
ii) **Kualiti output:** *Quality of outputs*	☐	☐	☐	☐	■
iii) **Kualiti impak:** *Quality of impacts*	☐	☐	☐	■	☐
iv) **Pemindahan teknologi/potensi pengkomersialan:** *Technology transfer/commercialization potential*	☐	☐	■	☐	☐
v) **Kualiti dan usahasama :** *Quality and intensity of collaboration*	☐	☐	☐	☐	■
vi) **Penilaian kepentingan secara keseluruhan:** *Overall assessment of benefits*	☐	☐	☐	☐	■

6. Abstrak Penyelidikan
(Perlu disediakan di antara 100 - 200 perkataan di dalam **Bahasa Malaysia dan juga Bahasa Inggeris**. Abstrak ini akan dimuatkan dalam Laporan Tahunan Bahagian Penyelidikan & Inovasi sebagai satu cara untuk menyampaikan dapatan projek tuan/puan kepada pihak Universiti & masyarakat luar).

Abstract of Research
(An abstract of between 100 and 200 words must be prepared in Bahasa Malaysia and in English). This abstract will be included in the Annual Report of the Research and Innovation Section at a later date as a means of presenting the project findings of the researcher/s to the University and the community at large)

Sila rujuk pada lampiran B

7. Sila sediakan laporan teknikal lengkap yang menerangkan keseluruhan projek ini. [Sila gunakan kertas berasingan]
Applicant are required to prepare a Comprehensive Technical Report explaning the project. (This report must be appended separately)

Sila rujuk Lampiran B

Senaraikan kata kunci yang mencerminkan penyelidikan anda:
List the key words that reflects your research:

Bahasa Malaysia	*Bahasa Inggeris*
Acoustic Emission (AE)	Acoustic Emission (AE)
Pemantauan Kesihatan Struktur	Structural Health Monitoring
Ujian Tanpa Musnah	Non-Destructive Testing (NDT)

8. Output dan Faedah Projek
Output and Benefits of Project

(a) * **Penerbitan Jurnal**
Publication of Journals
(Sila nyatakan jenis, tajuk, pengarang/editor, tahun terbitan dan di mana telah diterbit/diserahkan)
(State type, title, author/editor, publication year and where it has been published/submitted)

Sila rujuk Lampiran B

(b) **Faedah-faedah lain seperti perkembangan produk, pengkomersialan produk/pendaftaran paten atau impak kepada dasar dan masyarakat.**
State other benefits such as product development, product commercialisation/patent registration or impact on source and society.

Sila rujuk Lampiran B

* Sila berikan salinan/*Kindly provide copies*

(c) **Latihan Sumber Manusia**
Training in Human Resources

i) Pelajar Sarjana:
Graduates Students
(Perincikan nama, ijazah dan status)
(Provide names, degrees and status)

ii) Lain-lain:
Others

9. Peralatan yang Telah Dibeli:
Equipment that has been purchased

Tiada

DR. NORAZURA MUHAMAD BUNNORI
LECTURER
SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
14300 NIBONG TEBAL
PULAU PINANG.

Tandatangan Penyelidik
Signature of Researcher

13/09/2012

Tarikh
Date

UNIVERSITI SAINS MALAYSIA

Laporan Akhir Projek Penyelidikan Jangka Pendek

Acoustic Emission (AE) Techniques for The Damage Assessment of Structures

by
Dr. Nor Azura Mohammad Bunnori
Assoc. Prof. Dr. Megat Azmi Johari
Dr. Shahid Kabir

2012

Komen Jawatankuasa Penyelidikan Pusat Pengajian/Pusat
Comments by the Research Committees of Schools/Centres

Aktif dalam penyelidikan dan menghasilkan 2 (ISI) Journal.

Profesor Dr. Badorul Hisham Abu Bakar
Timbalan Dekan
Pengajian Siswazah & Penyelidikan
Pusat Pengajian Kejuruteraan Awam
Kampus Kejuruteraan
Universiti Sains Malaysia

14/9/2012

TANDATANGAN PENGERUSI
JAWATANKUASA PENYELIDIKAN
PUSAT PENGAJIAN/PUSAT
Signature of Chairman
[Research Committee of School/Centre]

Tarikh
Date

6. **Abstrak Penyelidikan**
(Perlu disediakan di antara 100 - 200 perkataan di dalam **Bahasa Malaysia dan juga Bahasa Inggeris.** Abstrak ini akan dimuatkan dalam Laporan Tahunan Bahagian Penyelidikan & Inovasi sebagai satu cara untuk menyampaikan dapatan projek tuan/puan kepada pihak Universiti & masyarakat luar).

Abstract of Research
(An abstract of between 100 and 200 words must be prepared in Bahasa Malaysia and in English). This abstract will be included in the Annual Report of the Research and Innovation Section at a later date as a means of presenting the project findings of the researcher/s to the University and the community at large)

Abstract:

Reinforced concrete (RC) has been facing several types of damage mechanism during their lifetime. The types of common defects in concrete structures are crack formation, corrosion, scalling and etc. Therefore a non destructive evaluation method such as Acoustic Emission (AE) is required for assessing the condition of the RC structures. AE testing in RC structures shows great potential in monitoring and assessing the health conditions of structures. AE is used as a tool to detect, identify, locate and quantify a variety of damage mechanism. Apart from an extensive literature studies had been done, this research had covered some tested of RC structures in locally and globally. A wide range of analysis had been explored in order to evaluate and quantify damage to enhance the research platform in Structural Health Monitoring (SHM) area. The evaluation methods that had been explored were acoustic wave velocity, Moment Tensor analysis (MTA) and intensity analysis. As a summary this research had been a triumphant study and the continuity of this research as shown in successfulness in Exploratory Research Grant Scheme (ERGS) application (RM110,000). Apart from that few publications has been published with the financial support from this USM Short term grant.

Abstrak:

Konkrit bertetulang telah menghadapi banyak mekanisma kerosakan sepanjang perkhidmatannya. Antara kerosakan yang normal pada struktur konkrit adalah pembentukkan retakan, kakisan besi tetulang, peyerpihan dan sebagainya. Justeru itu, kaedah penilaian tanpa musnah seperti *Acoustic Emission* (AE) amat diperlukan untuk menilai tahap kondisi struktur konkrit bertetulang. Penggunaan ujian AE pada konkrit tetulang telah menunjukkan potensi yang amat baik dalam memantau dan menilai tahap kesihatan struktur tersebut. AE telah digunakan bagi tujuan untuk mengesan, mengenalpasti, menentukan lokasi dan mengukur pelbagai tahap mekanisma kerosakan. Selain daripada kajian literatur mendalam yang dilakukan, penyelidikan ini telah membuat ujikaji ke atas konkrit bertetulang secara tempatan dan global. Penyelidikan yang luas dalam kaedah analisis telah dilakukan untuk mengukur tahap kerosakan bagi memantapkan pelantar penyelidikan dalam bidang pemantauan kesihatan struktur. Antara kaedah-kaedah penilaian yang telah dikaji dalam penyelidikan ini adalah halaju gelombang acoustic, analisis *Moment Tensor* (MTA) dan analisis keamatan. Kesimpulannya penyelidikan ini telah berjaya dilaksanakan dan kesinambungan daripada penyelidikan ini telah ditunjukkan dengan kejayaan mendapatkan geran *Exploratory Research Grant Scheme* (ERGS) bernilai RM110,000. Selain daripada itu, beberapa penerbitan juga dapat dihasilkan dengan bantuan kewangan daripada Geran Jangka Pendek USM ini.

7. **Sila sediakan laporan teknikal lengkap yang menerangkan keseluruhan projek ini.**

[Sila gunakan kertas berasingan]

Applicant are required to prepare a Comprehensive Technical Report explaning the project. (This report must be appended separately)

The main objective of this grant was to be a starting point in setting up an Acoustic Emission Technology (AET) platform in School of Civil Engineering, USM. Apart from this, this study also was designed to broaden the understanding of the Acoustic Emission Technique (AET) for use in local and global structural monitoring in order to provide a practical technique for the NDT in structural damage assessment. This technique is new in Malaysia and it is a great importance to have a significant platform with this technology as a health monitoring techniques would be beneficial as they would improve the confidence with which structural performance is assessed and predicted.

From the beginning of the grant received (2009) and up to this moment, the allocation had been used widely for the Final Year Project (FYP) and mixed-mode MSc. programme. In total five FYP's and two Msc. (mixed-mode) had graduated (2009-2011). Because of the overwhelming of the postgraduate students who were interested to explore in this particular research area this grant also had supported some financial of their research (lab-based experimental works). In total 3 PhD's students which are still on-going research up to this moment (2009-2012). In the final statement of the account it had shown that most of the allocation has been used in VOT 2700 to support the laboratory materials and testing.

Throughout the study, four citation index journals (SCOPUS) and one non citation journal (local) has been published. The allocation has been used wisely and solely for the research and students laboratory purposes. The allocation for VOT 2100 has been completed used wisely (allocation RM1000).

The objectives of this research were:

i. To set up an Acoustic Emission Technology (AET) platform as a damage assessment in School of Civil Engineering, Engineering Campus, USM. These includes in getting up a supports/advices from Physical Acoustic Ltd. in UK and USA and from local sole distributer of Physical Acoustic Sdn. Bhd. in Kuantan.

ii. To introduce a new technology as a health monitoring techniques that would be beneficial as AET would improve the confidence with which structural performance is assessed and predicted.

iii. This study is to broaden the understanding of the Acoustic Emission Technique (AET) for use in local and global structural monitoring in order to provide a practical technique for the NDT in structural damage assessment. This technique is new in Malaysia and it is a great importance to have a significant platform with this technology as a health monitoring techniques would be beneficial as they would improve the confidence with which structural performance is assessed and predicted.

Overall the objectives of this research were achieved and the initiation of applying more grants has been successful (Short Term and ERGS) in this particular research area.

8. Output dan Faedah Projek

Output and Benefits of Project

(a) * **Penerbitan Jurnal**

Publication of Journals

(Sila nyatakan jenis, tajuk, pengarang/editor, tahun terbitan dan di mana telah diterbit/diserahkan)

(State type, title, author/editor, publication year and where it has been published/submitted)

1. Shahiron Shahidan, Noorsuhada Md. Nor, Norazura Muhamad Bunnori, Analysis methods of acoustic emission signal for monitoring of reinforced concrete structure: A review, 2011 IEEE 7th International Collaquium on Signal Processing & Its Applications (CSSPA), 4-6 March 2011. [SCOPUS]
2. Shahiron Shahidan, Noorsuhada Md. Nor, Norazura Muhamad Bunnori, Overview of moment tensor analysis of acoustic emission signal in evaluation concrete structure, 2011 IEEE 7th International Collaquium on Signal Processing & Its Applications (CSSPA), 4-6 March 2011.[SCOPUS]
3. Noorsuhada Md. Nor, Norazura Muhamad Bunnori,Azmi Ibrahim, Shahiron Shahidan, Soffian Noor Mat Saliah, An observation of noise intervention into acoustic emission signal on concrete structure, 2011 IEEE 7th International Collaquium on Signal Processing & Its Applications (CSSPA), 4-6 March 2011. [SCOPUS]
4. Noorsuhada Md. Nor, Norazura Muhamad Bunnori,Azmi Ibrahim, Shahiron Shahidan, Soffian Noor Mat Saliah, An investigation on acoustic wave velocity on reinforced concrete beam in-plane source, 2011 IEEE 7th International Collaquium on Signal Processing & Its Applications (CSSPA), 4-6 March 2011.[SCOPUS]
5. Sakiah Abdul Kudus, Fairuz Wahida Zulkefli, Norazura Muhamad Bunnori, 2011, Global monitoring of reinforced concrete beam using acoustic emission technique, NDT SPECTRA, Issue No. 5, pg 239-244.

(b) **Faedah-faedah lain seperti perkembangan produk, pengkomersialan produk/pendaftaran paten atau impak kepada dasar dan masyarakat.**

State other benefits such as product development, product commercialisation/patent registration or impact on source and society

AE is well-suited to the study of the integrity of such structures since it is capable of continuous in-situ monitoring and offers the ability to detect a wide range of damage mechanisms in real time. Furthermore, AE offers the potential for the supply of qualitative and quantitative information concerning the condition of a structure via the application of a range of methods ranging from simple inference to intelligent signal analysis and classification techniques.

Monitoring the structural health condition at regular intervals can provide a full beneficial to the public as it can:

- Enable the detection and location of damage or degradation of structural components and provide this information to the operators and users of the structure quickly and comprehensibly.
- Allow structural degradation to be identified early prior to local failure.
- Prevent system failure.
- Help reduce maintenance costs.

UNIT KUMPULAN WANG PENYELIDIKAN/RU
JABATAN BENDAHARI KAMPUS KEJURUTERAAN
PENYATA KUMPULAN WANG
TEMPOH BERAKHIR 6/2012

Status Projek : AKTIF

Tajuk Projek : ACOUSTIC EMISSION (AE) TECHNIQUES FOR THE DAMAGE ASSESSMENT OF STRUCTURES

No Projek (Agensi) :

Pusat Pengajian : Pusat Pengajian Kejuruteraan Awam

Tempoh Projek : 2009 / 11 - 2011 / 12

No Akaun : 304 / 6039047

Penyelidik : NORAZURA MUHAMAD BUNNORI

Vot	Keterangan	Peruntukan Asal	Perbelanjaan Tahun Lalu	Peruntukan Semasa	Tanggungan	Belanja	Jumlah Belanja	Baki	%
11000	Gaji	12,806.00	$0.00	$0.00	$0.00	$0.00	$0.00	$12,806.00	0.00
		$12,806.00	**$0.00**	**0.00**	**$0.00**	**$0.00**	**$0.00**	**$12,806.00**	0.00
21000	PERJALANAN DAN SARA HIDUP	1,000.00	$932.60	$0.00	$0.00	$0.00	$0.00	$67.40	0.00
23000	PERHUBUNGAN DAN UTILITI	600.00	$0.00	$0.00	$0.00	$0.00	$0.00	$600.00	0.00
24000	SEWAAN	13,000.00	$8,650.00	$0.00	$0.00	$0.00	$0.00	$4,350.00	0.00
26000	BEKALAN BAHAN MENTAH	6,000.00	$0.00	$0.00	$0.00	$0.00	$0.00	$6,000.00	0.00
27000	BEKALAN DAN ALAT PAKAI HABIS	1,500.00	$17,986.60	$0.00	$874.00	$0.00	$874.00	($17,360.60)	0.00
29000	PERKHIDMATAN IKTISAS DAN HOSPITALITI	4,000.00	$8,429.20	$0.00	$2,000.00	$0.00	$2,000.00	($6,429.20)	0.00
		$26,100.00	**$35,998.40**	**0.00**	**$2,874.00**	**$0.00**	**$2,874.00**	**($12,772.40)**	0.00
		$38,906.00	**$35,998.40**	**$0.00**	**$2,874.00**	**$0.00**	**$2,874.00**	**$33.60**	0.00

UNIVERSITI SAINS MALAYSIA

LAPORAN KEMAJUAN PROJEK PENYELIDIKAN JANGKA PENDEK

PROGRESS REPORT OF SHORT TERM RESEARCH PROJECT

Sila kemukakan laporan kemajuan ini kepada Pejabat Pelantar Penyelidikan

☐ **6 bulan/** *6 months* ☐ **12 bulan/** *12 months* ■ **18 bulan/** *18 months*

Nama Ketua Penyelidik: Dr. Norazura Muhamad Bunnori
Name of Research Leader

Nama Penyelidik Bersama: PM. Dr. Megat Azmi Megat Johari & Dr. Shahid Kabir
Name of Co-Researcher

Pusat Tanggungjawab (PTJ): PP Kejuruteraan Awam (PPKA)
School/Centre

Tajuk Projek Penyelidikan: Acoustic Emission Technique (AE) for The Damage Assessment of Structures.
Title of Research Project

Jumlah Geran Diluluskan: RM 38,906.00 (Peruntukan Pertama: RM 24,837.00, Peruntukan Kedua: RM14,069)
Amount of Approved Grant

Baki Geran: RM 33.60
(sila sertakan penyata kewangan terkini)
Balance of Grant
[attach latest statements of accounts]

Tarikh Mula:
Date of Commencement of Project

0	1	1	2	2	0	0	9

Tarikh Tamat Asal:
Original Date of Completion of Project

0	1	1	2	2	0	1	1

Tempoh Lanjutan yang Diluluskan *(sekiranya berkaitan)*:
Approved Extension Period [if relevant]

Tarikh Permohonan *Date of Application*	**Tarikh Diluluskan** *Date of Approval*	**Tarikh Tamat Baru yang Diluluskan** *Date of Completion (following extension)*

Laporan Kemajuan dari Segi Kerja-kerja yang Telah Dijalankan:
Progress Report for All Conducted Work
(Sila sertakan Laporan Kemajuan yang berkaitan dan juga penerbitan yang telah dihasilkan)
(Kindly attach progress reports that are relevant as well as resulting publications)

Two MSc. (mixed mode) had been graduated which basically their dissertation project had involved a Laboratory work. The financial support was come from this short term grant. Two papers had been submitted for two different conferences Which were organized by Malaysian Society for Non Destructive Testing and IEEE. The Conferences were held in Kuala Lumpur (November 2011) and Langkawi (September 2011).

Ringkasan Penilaian Kendiri *Summary of Self Assessment*	Tidak Mencukupi *Inadequate* 1	2	Boleh Diterima *Acceptable* 3	Amat Baik *Very Good* 4	5
1. Pencapaian yang mungkin daripada objektif projek. *Probable achievement of project objectives*				/	
2. Pencapaian sebenar *Milestone achievement*					/
3. Kesesuaian kemajuan penyelidikan *Appropriateness of research progress*					/
4. Penggunaan Sumber Manusia *Utilization of human resources*			/		
5. Penggunaan kelengkapan penyelidikan *Utilization of research equipment*					/
6. Prestasi masa *Timing performance*				/	
7. Prestasi kewangan *Financial performance*				/	
8. Penilaian keseluruhan *Overall assessment*				/	

DR. NORAZURA MUHAMAD BUNNORI
LECTURER
SCHOOL OF CIVIL ENGINEERING
UNIVERSITI SAINS MALAYSIA
14300 NIBONG TEBAL
PULAU PINANG.

16/08/2012

Tandatangan Penyelidik
Signature of Researcher

Tarikh
Date

UNIVERSITI SAINS MALAYSIA

LAPORAN KEMAJUAN PROJEK PENYELIDIKAN JANGKA PENDEK

PROGRESS REPORT OF SHORT TERM RESEARCH PROJECT

Sila kemukakan laporan kemajuan ini kepada Pejabat Pelantar Penyelidikan

☐ **6 bulan/** *6 months* ■ **12 bulan/** *12 months* ☐ **18 bulan/** *18 months*

Nama Ketua Penyelidik: Dr. Norazura Muhamad Bunnori
Name of Research Leader

Nama Penyelidik Bersama: PM. Dr. Megat Azmi Megat Johari & Dr. Shahid Kabir
Name of Co-Researcher

Pusat Tanggungjawab (PTJ): PP Kejuruteraan Awam (PPKA)
School/Centre

Tajuk Projek Penyelidikan: Acoustic Emission Technique (AE) for The Damage Assessment of Structures.
Title of Research Project

Jumlah Geran Diluluskan: RM 38,906.00 (Peruntukan Pertama: RM 24,837.00)
Amount of Approved Grant

Baki Geran: RM 14,661.40 (pada Jan 2011, baki RM1,000)
(sila sertakan penyata kewangan terkini)
Balance of Grant
[attach latest statements of accounts]

Tarikh Mula:
Date of Commencement of Project

0	1	1	2	2	0	0	9

Tarikh Tamat Asal:
Original Date of Completion of Project

0	1	1	2	2	0	1	1

Tempoh Lanjutan yang Diluluskan *(sekiranya berkaitan)*:
Approved Extension Period [if relevant]

Tarikh Permohonan *Date of Application*	**Tarikh Diluluskan** *Date of Approval*	**Tarikh Tamat Baru yang Diluluskan** *Date of Completion (following extension)*

Laporan Kemajuan dari Segi Kerja-kerja yang Telah Dijalankan:
Progress Report for All Conducted Work
(Sila sertakan Laporan Kemajuan yang berkaitan dan juga penerbitan yang telah dihasilkan)
(Kindly attach progress reports that are relevant as well as resulting publications)

Sila lihat Lampiran A

Ringkasan Penilaian Kendiri *Summary of Self Assessment*	Tidak Mencukupi *Inadequate* 1	2	Boleh Diterima *Acceptable* 3	Amat Baik *Very Good* 4	5
1. Pencapaian yang mungkin daripada objektif projek. *Probable achievement of project objectives*				/	
2. Pencapaian sebenar *Milestone achievement*					/
3. Kesesuaian kemajuan penyelidikan *Appropriateness of research progress*					/
4. Penggunaan Sumber Manusia *Utilization of human resources*			/		
5. Penggunaan kelengkapan penyelidikan *Utilization of research equipment*					/
6. Prestasi masa *Timing performance*				/	
7. Prestasi kewangan *Financial performance*				/	
8. Penilaian keseluruhan *Overall assessment*				/	

[signature] 22/02/2011

Tandatangan Penyelidik — **Tarikh**
Signature of Researcher — *Date*

Lampiran A

Laporan Kemajuan dari Segi Kerja-kerja yang Telah Dijalankan:

Progress Report for All Conducted Work
(Sila sertakan Laporan Kemajuan yang berkaitan dan juga penerbitan yang telah dihasilkan)

(Kindly attach progress reports that are relevant as well as resulting publications)

Three PhD's students currently registered under the research area. Apart from that, three FYP students and two MSc. (mixed mode) has also been registered under this research. All of this students are doing a laboratory base research and the needed of materials are highly in demand. The amount of money that has been allocated (first allocation) has been fully used to buy materials such as wood, cement, aggregates, steel, rebar and etc.

Four papers has been submitted and accepted in IEEE 7th International Collaquium on Signal Processing & Its Applications (CSSPA). All accepted papers will be published in the colloquium proceedings and IEEExplore and will be published as chapter(s) or full paper in refereed publications. The four papers are listed as follows and a copy of these paper are attached:

1. Shahiron Shahidan, Noorsuhada Md. Nor, Norazura Muhamad Bunnori, Analysis methods of acoustic emission signal for monitoring of reinforced concrete structure: A review, 2011 IEEE 7th International Collaquium on Signal Processing & Its Applications (CSSPA), 4-6 March 2011.
2. Shahiron Shahidan, Noorsuhada Md. Nor, Norazura Muhamad Bunnori, Overview of moment tensor analysis of acoustic emission signal in evaluation concrete structure, 2011 IEEE 7th International Collaquium on Signal Processing & Its Applications (CSSPA), 4-6 March 2011.
3. Noorsuhada Md. Nor, Norazura Muhamad Bunnori,Azmi Ibrahim, Shahiron Shahidan, Soffian Noor Mat Saliah, An observation of noise intervention into acoustic emission signal on concrete structure, 2011 IEEE 7th International Collaquium on Signal Processing & Its Applications (CSSPA), 4-6 March 2011.
4. Noorsuhada Md. Nor, Norazura Muhamad Bunnori,Azmi Ibrahim, Shahiron Shahidan, Soffian Noor Mat Saliah, An investigation on acoustic wave velocity on reinforced concrete beam in-plane source, 2011 IEEE 7th International Collaquium on Signal Processing & Its Applications (CSSPA), 4-6 March 2011.

Total grant granted is RM 38,906.00 and the first allocation of RM24,837.00 has been completely used. The balance of RM 14,069.00 is highly in needed to proceed with the research to fulfill the students need before the application of RU grant in March.

JABATAN BENDAHARI
KAMPUS KEJURUTERAAN

UNIVERSITI SAINS MALAYSIA

NYATA KUMPULAN WANG
RAKHIR : 31/12/2010

l Akaun :304.PAWAM.6039047	Tajuk Projek :	ACOUSTIC EMISSION (AE) TECHNIQUES FO	
yelidik : NORAZURA MUHAMAD BUNNORI	Panel:	Geran Jangka Pendek	
'engajian: PUSAT PENGAJIAN KEJ AWAM	Penaja:		
npoh : 2009/11 hingga 2011/12	Jumlah peruntukan/geran :	0.00	

		Jumlah Peruntukan (a)	Perbelanjaan Sehingga 31/12/2009 (b)	Peruntukan Semasa 2010 (c)	Tanggungan Semasa 2010 (d)	Perbelanjaan Semasa 2010 (e)	Jumlah Perbelanjaan (f)=(d+e)	Baki Peruntukan Semasa (c)- (f)
11	Gaji Kakitangan Awam	8,537.00	0.00	8,537.00	0.00	0.00	0.00	8,537.00
21	Perbelanjaan Perjalanan & Sara Hidup	500.00	0.00	500.00	0.00	0.00	0.00	500.00
23	Perhubungan & Utiliti	300.00	0.00	300.00	0.00	0.00	0.00	300.00
24	Sewaan	9,000.00	0.00	9,000.00	0.00	6,000.00	6,000.00	3,000.00
26	Bahan Mentah & Bahan Untuk Penyelenggaraan & Pembaikan	4,000.00	0.00	4,000.00	0.00	0.00	0.00	4,000.00
27	Bekalan & Alat Pakai Habis	1,500.00	0.00	1,500.00	0.00	4,175.60	4,175.60	-2,675.60
29	Perkhidmatan Iktisas & Hospitaliti	1,000.00	0.00	1,000.00	0.00	0.00	0.00	1,000.00
	JUMLAH	24,837.00	0.00	24,837.00	0.00	10,175.60	10,175.60	14,661.40

2/14/2011 11:38 AM

UNIVERSITI SAINS MALAYSIA

LAPORAN KEMAJUAN PROJEK PENYELIDIKAN JANGKA PENDEK
PROGRESS REPORT OF SHORT TERM RESEARCH PROJECT

Sila kemukakan laporan kemajuan ini kepada Pejabat Pelantar Penyelidikan

- [x] 6 bulan/ *6 months*
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Name of Research Leader

Nama Penyelidik Bersama: PM. Dr. Megat Azmi Megat Johari & Dr. Shahid Kabir
Name of Co-Researcher

Pusat Tanggungjawab (PTJ): PP Kejuruteraan Awam (PPKA)
School/Centre

Tajuk Projek Penyelidikan: Acoustic Emission Technique (AE) for The Damage Assessment of Structures.
Title of Research Project

Jumlah Geran Diluluskan: RM 38,906.00 (Peruntukan Pertama: RM 24,837.00)
Amount of Approved Grant

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1. Pencapaian yang mungkin daripada objektif projek. *Probable achievement of project objectives*			/		
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11	Gaji Kakitangan Awam	8,537.00	0.00	8,537.00	0.00	0.00	0.00	8,537.00
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Analysis methods of acoustic emission signal for monitoring of reinforced concrete structure: A review

Shahidan, S.[a], Md Nor, N.[b], Bunnori, N.M.[a]
[a] School of Civil Engineering, Universiti Sains Malaysia (USM), Seri Ampangan, Seberang Perai Selatan, 14300 Nibong Tebal, Pulau Pinang, Malaysia
[b] Faculty of Civil Engineering, Universiti Teknologi MARA(Uitm), 13500 Permatang Pauh, Pulau Pinang, Malaysia

Abstract

This paper summarized two types of modern Acoustic Emission Analysis (AEA) for damage detection of reinforced concrete (RC) structure beneficially to accelerate analysis part particularly for newly researcher, namely wavelet and b-value analyses. Both methods are based on analysing of acoustic emission (AE) signals. The concept and significant of these methods also have been described in detail to give clear picture regarding to the structural performance assessment. The derivation of specific formulas and case studies based on other researchers work also included to prove the applicability and effectiveness of the chosen AE analyses. Applications of these AE analyses in RC structure also have been discussed and future research work has been recommended. © 2011 IEEE.

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Analysis Methods of Acoustic Emission Signal for monitoring of Reinforced concrete structure: A review

Shahiron Shahidan[#1], Noorshuhada Md Nor*[2], Norazura Muhamad Bunnori[#3]
[1,3]School of Civil Engineering, Universiti Sains Malaysia (USM), Seri Ampangan, Seberang Perai Selatan
14300 Nibong Tebal, Pulau Pinang, Malaysia
[#1]shahironshahidan@gmail.com
[#3]cenorazura@eng.usm.my

*[*2]Faculty of Civil Engineering, Universiti Teknologi MARA(Uitm)*
13500 Permatang Pauh, Pulau Pinang, Malaysia
[*2]idanur211@yahoo.com

Abstract— **This paper summarized two types of modern Acoustic Emission Analysis (AEA) for damage detection of reinforced concrete (RC) structure beneficially to accelerate analysis part particularly for newly researcher; namely wavelet and b-value analyses. Both methods are based on analysing of acoustic emission (AE) signals. The concept and significant of these methods also have been described in detail to give clear picture regarding to the structural performance assessment. The derivation of specific formulas and case studies based on other researchers work also included to prove the applicability and effectiveness of the chosen AE analyses. Applications of these AE analyses in RC structure also have been discussed and future research work has been recommended.**

Keywords-component; Acoustic emission Signal, Wavelet analysis, b- value, concrete structure, cracking

I. Introduction

In general, damage mechanisms on reinforced concrete (RC) structure can be analysed conventionally by using the acoustic emission (AE) parameters. Conventional method is rudimentary analysis and simplest method for AEA. Modern method as well as signal-based method needs the interpretation by an expert manually processing the data including a time consuming picking of the signal onsets by hand [1]. For instance, [1] listed steps of modern AEA that relate to fracture; including the analysis of mechanical data and the acoustic emission rate, the localization of acoustic emission, thirdly topography evaluation of fracture plan and finally fracture mechanical studies based on the AE waveforms.

The methods of AEA will be improved by time to time but the knowledge of basic analysis that was used by previous researchers will assist and as a platform for a new researcher to cater, capture and upgrade the new method; which comply with current needs. To enhance the AEA, there are several general advantages and limitation for applying AEA which relate to the AE technique should be understood. Mainly, AE is generated by the material itself [2]. Meanwhile, [3] reported the advantages of acoustic emission technique as follows: gives dynamic characteristics of active defects; the entire of structure can be covered in single inspection (volume technique); AE data gives real time record of progressing damage; can be used to detect location of active flaws in large structure; the sensor can be placed anywhere on the test specimen.

Major problem by using AE technique is noise disturbance in AE data analysis, which suitable threshold must be set earlier to eliminate or reduce this interference; where the sensors has to be placed on the structure under test [3],[4] has reported three disadvantages of acoustic emission based on several practical as follow; difficulty of setting the threshold due to the same damage type can emit AE signal with vary amplitudes; AE signal in composites suffer from high attenuation (signals close to the sensor are stronger than those generated farther away); frequency response of the transducers frequencies which is spaced several decibels only, will be magnified differently.

The limitations of the system will influence the analysis part. To get the accurate data, shortcoming of the system such as interference of noise to the data collected must be prevented, to distinguish between noise and genuine significant signal is not easy. For instance, filtering the noise by choosing the right threshold level prior to testing can be used to prevent the disturbance of noise in the signals. Otherwise, the selection of analysis part particularly for reinforced concrete (RC) structure which is heterogeneous material is important.

Thus, this paper reviewed the two types of acoustic emission analysis (AEA) for damage detection of reinforced concrete (RC) structure to accelerate analysis AE data. Two types of AE analyses have been considered namely wavelet transform and b-value analyses. These two types of AE analysis were then described in detail for comprehensive study and deeply understanding on the selected analyses for generous damage mechanism of RC structure.

II. AE Analysis : Review and Case Studies

There are many techniques have been developed to interpret and to analyse the AE data. The most appropriate approach for any AE testing situation is dependent on a number of factors. Those include the suitability of the AE analysis for the particular selected material, size of the specimen, type of loading would be applied, purpose of the monitoring, and so forth. Two modern AE analyses (Wavelet analysis and b-value analysis) have been discussed in the following which include the introduction, significant, formula and case study of the selection analysis:

A. *Wavelet Analysis*

1) *Introduction:*

Based on the former research, wavelet transform analysis has been developed from the previous numerical method known as a Fast Fourier Transform (FFT). The characteristic of the FFT method similar with the wavelet transform which is finding the frequency of signal components, but this traditional method can only extracted from the complete duration of a signal. However the wavelet analysis is well suited technique to detect and analyze AE events occurring to different scales of signal according to the duration of time.

Furthermore, Wavelet transform has been proven the ability to defeats many of the limitations of the widely used Fourier transform (FT). Upon that matter, it has gained the popularity as an efficient of the signal processing in monitoring system [5],[6],[7]. Basically, wavelet transform analysis can be defined as a time frequency or discrete (digital) signal and also reported that, wavelet analysis is a mathematical function that cut up data into different frequency of AE waveforms [5],[6],[8]. Due to the modern developments of AE analysis technique in concrete structure, wavelet transforms has recently been consume and perfect tool technique of analysis for concrete structure damage detection and also in structural health monitoring.

2) *Significant of the Analysis:*

This type of analysis is significantly important due to the development raise new problem of cases and therefore, analytical techniques such as wavelet analysis are highly demand to solve the current problem. This owing to the high of AE signal rates and events at relative high frequency from 20kHz up to several MHz[9]. Mostly, this was occurred during the extremely damage in concrete structure such as, building due to earthquake loading and bridge owing to increase traffic loading. According to [6], the main objective of this method is to develop the analytical method of AE signal analysis based on the rate of damage for ensuring the safety of structural integrity during the severe environmental loading. In addition, wavelet Transform analysis also significant in the AE signals waveforms as an AE filter technique to avoid and reducing the noise from the signal. The design of wavelet filters to enhance the signal to noise ratio in the AE signal analysis [9]. The elimination of low frequency noises by using the wavelet algorithm show the satisfy result during analysis of AE signal.

3) *Formulation:*

As the most recent area in mathematical solutions, wavelet transforms is very popular and useful method in AE signal analysis. Therefore, it comes in three different forms, continuous wavelet transforms (CWT), and discrete wavelet transforms (DWT) and wavelet Packet.

Continuous wavelet transforms (CWT)

The CWT of signal *x(t)* by using the mother wavelet □(t) is :

$$WT(a,\tau) = \frac{1}{\sqrt{|a|}} \int x(t)\psi * \left(\frac{t-\tau}{a}\right) dt \qquad (1)$$

Where, a is the scaling and τ is the translation, and $*$ is the complex conjugate of , called mother wavelet or basic function. It represented as $\psi(t) = 2\psi\,(2t - k)$

CWT will modify the length of the wavelet at the different scale frequency to analyze the signal with the information of localization. If the scaling a value is lower than 1(high frequency), the result is a good time resolution. Similarly, if the scaling value a is greater than 1(low frequency), the time resolution is poor which means a signal with rapid changes in the time domain will present at high frequency range in frequency domain[6,10]. According to the improvement of the traditional method short time Fourier transform (STFT), the relation between scale and frequency to generate a time frequency spectrum are presented as

$$f = \frac{\Delta f}{a \times s} \qquad (2)$$

Where as Δf is the center frequency of the wavelet and s, is the sampling interval [10]. Furthermore for an inverse wavelet transform, the mother wavelet has to satisfy the admissibility condition and it define as

$$\int \frac{|\psi(\omega)|^2}{|\omega|} d\omega < +\infty \qquad (3)$$

Where $\psi(\omega)$ is the stand for Fourier transform of $\psi(t)$. Therefore Equation 1 can be presented as

$$WT(a,\tau) = \langle x(t), \psi * (t)\rangle \qquad (4)$$

Where $x(t)$, as the signal and $_{a,\tau}(t)$ as the translated and dilated wavelets [6],[10].

Discrete wavelet transforms (DWT)

The discrete wavelet transform (DWT) is a tool for breaking down the signals into the elementary block and mutually orthogonal set of wavelets. In DWT the wavelet are build from the scaling function which is orthogonal set to the discrete translation. This is similarly to the Fourier transform signal in term of elementary periodic waves. The case where DWT in the orthogonal wavelet the formula is define as

$$c_{m,n} = \int_{-\infty}^{+\infty} x(t)\Psi_{m,n}(t)\, dt \qquad (5)$$

Where the synthesis of the signal is

$$x(t) = \sum_m \sum_n c_{m,n}\, \Psi_{m,n}(t) \qquad (6)$$

The setting of time scaled and time shifted wavelet by using the mother wavelet can be obtained the *baby wavelet* and defines as

$$\Psi_{m,n}(t) = 2^{m/2}\Psi\,(2^m t - n) \qquad (7)$$

However the case due to the orthonormal wavelets function define as

$$c_{m,n} = \int_{-\infty}^{+\infty} x(t)\Psi_{m,n}^{*}(t)\, dt \quad (8)$$

Here orthonormal wavelet function obtained by shifting and dilating from mother wavelet, (9)

$$\Psi_{m,n}(t) = 2^{-m/2}\Psi\,(2^{-m}t - n)$$

In the orthonormal basis the signal *x(t)* consist of a countable infinite set of wavelet. The signal formulation is define as

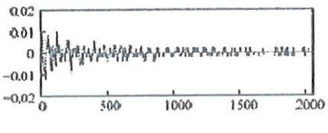
$$x(t) = \sum_{m=-\infty}^{+\infty} \sum_{n=-\infty}^{+\infty} C_{m,n}\,\Psi_{m,n}(t) \quad (10)$$

This formulation is the basic of DWT decomposition formulation [10]. Detail information about the wavelet theory and application can be found in the other note [5],[6],[8],[9],[10].

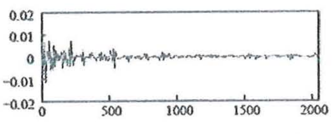
4) Case Study:

The previous research proves that, wavelet analysis can also be used to perform denoising of the response AE signals as presented in Fig. 1a and 1b, which is the result illustrated that the number of AE occurrences clearly increase with the increase in loading [16]. In addition, owing to the denoising of the AE signal, this method also can detect the tools failure in turning process [11]. Beside that, wavelet transform analysis can classify the classes of damage structure level based on the AE signal waveforms due to the fiber fracture, matrix cracking mode I and mode II disbanding [8]. Furthermore, the methods are applicable as valuable tool to the analysis of fatigue and failure in materials also continuous monitoring of damage growth in determination of fracture type [9].

It can be concluded that, this type of analysis is effectives and useful for detecting the damage of the concrete structure due to the AE signal waveforms. This was proved by the previous researchers about the application in the AE signal for concrete structure. Therefore, wavelet analysis has the potential of becoming an effective tool for detection of damage mechanisms and health monitoring of structure for the natural frequencies are irregularly changing [17].



(a)AE Signal of Specimen



(b) AE Signal Denoised by wavelet

Fig. 1 Comparison of normal AE signal with the Denoised AE signal[16]

B. b-value analysis

1) Introduction:

In AEA, the applications of b-value are not commonly employed as well like wavelet analysis and other conventional methods. This type of method is still needs a further investigation on the global application in AE.

b-value analysis is defined as the Log-linear slope of frequency magnitude distribution of AE. Beside that, it also familiar as a statistical method used to look at parametric AE data, and this relationship was established and developed by Gutenberg and Richer since 1949. Basically it's constitutes the scaling and magnitude distribution of AE and measuring the relative number of small and large AE which are signatures of localized failure in material under stress [12],[13].

2) Significant of The Analysis:

The significance of this analysis is as furnish tool to enable the researcher to diagnose the degrees and type of degradations of the concrete structure from AE technique [12]. The details application of b-value analysis can differentiate the type of cracks generated from the type of AE signals with the varying amplitude. For instance, microcracks generate a large number of events with the small amplitude while for the macrocracks, the events are lesser and amplitude will be larger. Beside that it also can quantify the degree of damage index for global concrete structure such as pier and beam due to the earthquake loading [14].

3) Formulation:

Usually, b-value analysis is computed by utilizing the cumulative frequency magnitude distribution data and the application of Gutenberg Richer relationship was applied and widely used in seismology. The equation presented by [12],[13].

$$\log_{10} N = a - bM \quad (11)$$

Where as, M is the Richter magnitude of the event, N is the incremental frequency, *a* an empirical constant and *b* is the b-value which is ~ 1.0. The value of M is proportional to the logarithm of the maximum amplitude A_{max} recorded in a seismic trace. In the AE method, the same principle can be applied to determine the scaling of the amplitude distribution of the AE waves during the fracture process. In term of AE technique, the formula was modified as [12]

$$\log_{10} N = a - bA_{max} \quad (12)$$

Where as; A_{max} is the peak amplitude of the AE event in decibels and the formula presented as [12].

$$A_{max} = 10\log_{10} A_{max}^{2} = 20\log_{10} A_{max} \quad (13)$$

However, to evaluate the slope failure and facture process, [14] was improving the formula to *improve b-value* (*Ib-value*). This formulation is more to statistical analysis such as mean and standard deviation for each of AE amplitude set. The formula defined as

$$Ib = \frac{\log N(\mu - \alpha_1\sigma) - \log N(\mu - \alpha_2\sigma)}{(\alpha_1 + \alpha_2)\sigma} \quad (14)$$

Where, σ is the standard deviation; μ is the mean value of the amplitude distribution; α_1 is coefficient related to the smaller amplitude and α_2 is coefficient related to the fracture level [12].All these formulation are applicable for analysis the degree and type of degradation for damage mechanisms.

4) Case Study:

Referring to [12] research work, the total number of event throughout a loading cycle was divided in group of channel. The graph of log frequency-magnitude was plotted and their linear trend of graph was calculated using the least-square method of fitting curve. The slope of linear graph represented the b-value as can be seen in Fig. 2. These b-values for the whole load cycle were then plotted to versus time, to determine the number of events forming the groups on which the calculation based as shown in Fig. 3. These figures were indicated the example calculation of b-value for channel 2 that was done by Colombo (2003) for assessing Damage of reinforced concrete beam[12].

This trend of b-value graph has to be plotted for each cycle of load test and for each channel. Upon that matter, the pattern of the graph was clearly indicated the crack forming. When the graph presented a clear pattern, the maximum values were indicated and formed the microcrack. Beside that, once the external macrocrack formed, the patterns of the graph will scattered and shown the less clear compare to the microcrack stage. This analysis implies that, the b-values analysis are pointed and provides the information of the structure condition, from the beginning of microcracking stage up to the macrocracking process.

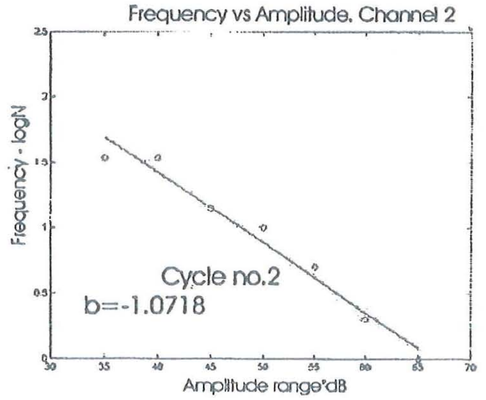


Fig. 2 Example of calculation of *b*-values for Channel 2 during loading cycle Number 2[12]

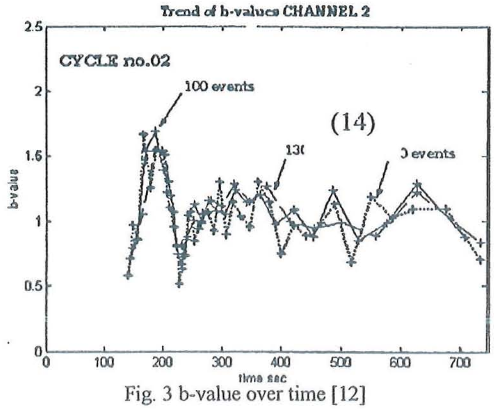


Fig. 3 b-value over time [12]

The minimum and maximum b-value has been considered for each cycle load in failure phase. The whole cycle and channel was plotted to reveal the variation of the value and the formation of micro and macro crack. This was presented in Fig. 4 by the Colomb(2003),the minimum b-value trend to formed macrocrack while as the maximum b-value trend implies microcrack growth[12].

Finally [12] and the research committees, was summarized the quantitative result based on the analysis of each load cycle and each channel in table 1.

From this case study, it was proved that, b-value is useful and provides information about the beginning of the crack up to the failure fracture.

According to the table 1, the minimum value of b value is shown the trend to macro cracks formed; while for the maximum value refers to the micro crack growth. Thus, it can be concluded that, b-value analysis is very useful for interpreting data obtained by a local and global monitoring of concrete structure. In addition, this analysis also able to quantify the level damage of concrete structure such as beam and pier due to variety type of loading analysis [12], [13], [14], [15].

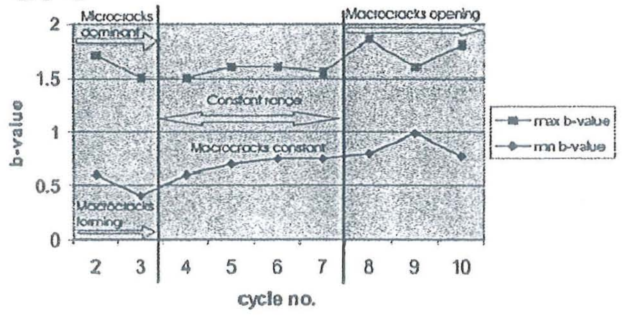


Fig. 4 Variation of maximum and minimum b-Value for the whole load cycle [12]

TABLE I
QUANTITATIVE ANALYSIS RESULT [12]

1.0<*b*-value<1.2	Implies that the channel is very near to a large crack; i.e.,macrocracks forming
1.2<*b*-value<1.7	Uniformly distributed cracking; i.e., macrocracks are constant
b-value>1.7	Microcracks are dominant or macrocracks are opening

III. Conclusion and Recommendation

In a nutshell, this paper has been reviewed modern types of AEA for damage detection and assessment of reinforced concrete structure. These methods of analysis provided several advantages over the conventional method. The details conclusions were made based on the each type of analysis.

Wavelet analysis	this method is able to utilize in AE analysis and capable to assess and evaluate the damage mechanisms in concrete structure.
b-Value	this method is provided the information on the cracking process from the initial stage of cracking up to the failure stage of fractures.

From the above matter, the global conclusion can be made that, the two type of AEA are available to employ in evaluation and detection the damage mechanisms level of reinforced concrete structure and the stress changes in the structure material. However, these types of analysis have their own characteristic and advantages due to the evaluations of damage mechanism. Thus, the selections of the method are significant to evaluate the detail process of fracture failure in concrete structure.

For future research, detail evaluation for each type of AEA should be carried out which includes the operational condition rather than limitation to laboratory test only for representative structure until final fracture

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An investigation on acoustic wave velocity of reinforced concrete beam in-plane source

Nor, N.Md.[a], Muhamad Bunnori, N.[b], Ibrahim, A.[a], Shahidan, S.[b], Saliah, S.N.M.[a]
[a] Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM), 13500 Permatang Pauh, Pulau Pinang, Malaysia
[b] School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia (USM), Seri Ampangan, Seberang Perai Selatan, 14300 Nibong Tebal, Pulau Pinang, Malaysia

Abstract

This paper is presented an investigation on acoustic wave velocity of reinforced concrete beam in-plane source based on AE waveform analysis. Pencil Lead Fracture (PLF) was used to generate sudden release of stress at selected source location. Three threshold levels were considered for determining wave velocity in RC beam. It can be concluded that the wave velocity was dependent to the threshold levels, high threshold level would prolong the TOA of the wave and the velocity would be reduced; which the wave travels in the RC beam at velocities in the range 2410 m/s to 4000 m/s. The wave velocity also decreased as the distance from individual sensor to synchronize sensors increased. © 2011 IEEE.

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An Investigation on Acoustic Wave Velocity of Reinforced Concrete Beam In–Plane Source

Noorsuhada Md Nor[#1], Norazura Muhamad Bunnori[*2], Azmi Ibrahim[#3], Shahiron Shahidan[*4], Soffian Noor Mat Saliah[#5]
[#]*Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM), 13500 Permatang Pauh, Pulau Pinang, Malaysia.*
[1]idanur211@yahoo.com
[3]azmii716@salam.uitm.edu.my
[5]pyan_noor@yahoo.com.sg

[*] *School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia (USM), Seri Ampangan, Seberang Perai Selatan, 14300 Nibong Tebal, Pulau Pinang, Malaysia.*
Address Including Country Name
[2]cenorazura@eng.usm.my
[4]shahironshahidan@gmail.com

***Abstract*—This paper is presented an investigation on acoustic wave velocity of reinforced concrete beam in-plane source based on AE waveform analysis. Pencil Lead Fracture (PLF) was used to generate sudden release of stress at selected source location. Three threshold levels were considered for determining wave velocity in RC beam. It can be concluded that the wave velocity was dependent to the threshold levels, high threshold level would prolong the TOA of the wave and the velocity would be reduced; which the wave travels in the RC beam at velocities in the range 2410 m/s to 4000 m/s. The wave velocity also decreased as the distance from individual sensor to synchronize sensors increased.**

***Keywords*— acoustic emission, wave velocity, AE source, in-plane**

I. Introduction

Acoustic Emission (AE) is a phenomenon of a transient stress waves resulting from a sudden release of elastic energy, caused by mechanical deformations, initiation and propagation of microcracks, dislocation movement, and other irreversible changes in material [1]. AE sensors are used to detect the acoustic waves at the surface of a structure, produced by AE events either on the surface or in the bulk of the material [2].

There are two methods normally used to analyse the output either by conventional or quantitative. Conventional method is easily to analyse due to parameter-based compared to quantitative method which based on the analysing of the waveform or signal-based. There are two types of signals in AE system; namely burst and continuous signals. Burst signal is separate type of signals of a very short duration (in the range of a few microseconds (μs) to a few miliseconds (ms)) and the broad frequency domain spectrum. Meanwhile the continuous signal is emitted close to each other or the burst is very high rate the signals occurred very close and sometimes even overlap. When the AE signal or output is transmitted in a structure, an array is identified. The output is always represented in waveform which has information on source location.

A key to compute source location is by determination of the wave velocity of the wave propagation in a structure is vital to take under consideration in AE technique. According to Muhamad Bunnori et al. [3], if wrong wave velocity was used either owing to poor assumption or triggering of the system, it would affect to the determination of the source location. Thus accurate wave velocity is important for source location and prior to any AE test would be carried out.

The AE wave velocity can be determined by estimating the time of arrival (TOA) of the wave propagating in the structure; normally based on the threshold level. It is impossible to get the same TOA as the wave emitted by fracture and recorded at each sensor; the source location can be calculated is defined by the time of the initiation of rupture or crack and the source position in Cartesian coordinates (x, y, z) [4]. Typically, the propagation of wave in concrete is represented in two types; longitudinal and shear wave. Longitudinal wave is known as bulk wave (L – wave or P – wave); which the wave travels in the material and shear wave (S-wave) is travelled along the surface of the specimen. The first TOA of the elastic wave at each sensor is the onset time of the P-wave. If the onset of the S-wave is detectable this information can be used either in combination with or instead of the P-wave onset. S-wave is challenging to determine due to the distance between sensor and receiver is only few wavelengths, the onset of the S-wave is hidden in the P-wave [5]. Generally, S-wave is normal and P-wave is parallel to the propagation of wave direction. Onset time determination can be carried out visually or automatically by picking algorithm and depends on the onset definition itself.

In this paper, varies threshold levels were performed to determine the TOA and wave velocity in the reinforced concrete beams with shorter source-to-sensor distance. Very little attention has been paid for shorter distance between sensors and sensor to source distance. An AE source was specified and focused on in-plane of the arrangement of sensors face.

II. Experimental Procedure

A. Preparation of Beam Specimen

The concrete beam was prepared for concrete strength of 40 N/mm^2. The beam was made up of cement, fine aggregate, coarse aggregate and water by weight with the proportion of 1:2:2.9:0.57, respectively; then cured in water tank for 28 days. In this research, the maximum size of aggregate was used is 20 mm. The size of the beam is 100 mm width, 100 mm thick and 500 mm length. Two high strength steel bars were embedded in the concrete from 20 mm of the bottom edge of the concrete; to strengthen the tension part would be used for flexural test later that would not mentioned here. Two 6 mm diameter of mild steel bars were used as hanger bars and stirrups.

B. Acoustic Emission System

Acoustic emission (AE) was monitored using a MicroSAMOS (µSAMOS) supplied by Physical Acoustic Corporation (PAC). The system consists of integral preamplifier acoustic emission sensors (transducers) R6I (40 – 100 kHz); a notebook acoustic emission system board (8 (channels) x 16 (hubs) bit acoustic emission channels, low peak and high peak filters, 2 MHz bandwidth, auto sensor test (AST), time definition display (TDD), digital signal processor (DSP) and waveform module; personal computer memory card international association (PCMCIA) interface card; cables; internal and external parametric cable set; a notebook personal computer with full suite of AEWin Software; universal serial bus (USB) license key; and magnetic clamps. The acquisition parameters in the AEWin software were summarized in Table 1.

C. Wave Velocity Test

Prior to wave velocity test carried out, three pair thin plates were prepared to attach the sensors S1, S2 and S3 with the specific distance between pair of plates is 45 mm. The beam surface was grinded smoothly to ensure good connectivity between sensors and beam surface. The plates were then fixed to the beam surface using epoxy and hardener. To ensure the sensors coupled to the specimen, a thin layer of grease (couplant) was applied between sensors and the specimen surfaces. The magnetic clamps were used to safeguard the sensors; which sensors held in position in magnetic clamps; then the magnetic clamps properly griped to the steel plates. In this experimental work, three R6I sensors with 50 kHz resonant frequency were used. Acoustic emission sensors are transducers that convert the mechanical waves into electrical signal, where the information about the existence and location of possible damage or stress released sources can be obtained. The specification and feature of the sensor is shown in Table 2.

One of the important signal parameters for determining wave velocity is amplitude. Signal amplitude is defined as the magnitude of the peak voltage of the largest excursion attained by the signal waveform from single emission event [1].

TABLE I
AE Test Parameters

Parameter	Value
Hit definition time (HDT)	2000µs
Peak definition time (PDT)	1000µs
Hit lockout time (HLT)	500µs
Threshold	45dB
Preamplifier (R6I)	40dB
Bandpass data acquisition filter	400kHz
Sample rate	100ksps
Analog filter (lower)	1kHz
Gain	0dB
Pre-trigger	250,000
Waveform set up length	1k

Amplitude is reported in decibels (dB) to measure signal size and typical AE signal is represented as a voltage versus time curve. Voltage is converted to dB using the following equation:

$$A = 20 \log (V/V_{ref}) \quad (1)$$

Where: A is an amplitude (dB), V is voltage of peak excursion and V_{ref} is the reference voltage. Generally the dB scale runs from 0 to 100 (Xu, 2008). In relationship between threshold level and amplitude, preamplifier should be considered; where equation below can be used to calculate amplitude:

$$\text{Threshold} = \text{Amplitude} - \text{Preamplifier} \quad (2)$$

A schematic diagram of the test set up in a linear structure is shown in Fig. 1. The AE source was identified on the in-plane of the sensors arrangement or source parallel to sensor face. Three sensors were mounted in a symmetrical arrangement on the RC beam (see Fig. 1) using grease as a couplant with the same spacing of 100 mm centre to centre. Prior to test, calibration check was carried out as well as the sensitivity measurement using a Hsu-Nielsen (H-N) technique, close to each sensor. H-N technique is used to ensure that the sensor and the specimen are in a good contact to provide an adequate result throughout the test. In addition, high sensitivity is another important requirement for AE sensors [6]. In this experiment, a pencil with a Nielson shoe was used to break a 0.5 mm 2H lead to generate acoustic waves. During experimental, the major drawback arose was calibration of AE sensors as well as sensitivity checking where the amplitude must be at least within $\pm$ 3 dB in different. This check is important due to possibility for variation in sensor characteristics with time, operation and environmental conditions [7].

To generate the acoustic wave velocity, PLF was carefully performed at 100 mm from sensor 1 known as artificial AE source. When the lead breaks, the stress on the surface of the specimen where the lead is touching is suddenly released. It is important to handle the pencil properly during break the lead against the testing specimen to get significant value. Improper handle of the pencil would give imprecise value; which affect to the TOA.

The rudimentary determination for location calculation is based on time-distance relationship implied by the velocity of the sound wave [4]; where the absolute arrival time, t, of a hit in an event can combine with the velocity, v (v is P-wave velocity [6], of the sound wave to yield the distance, d, from sensor to the source as represented by

$$d = v\,t \qquad (3)$$

Generally the distance between two sensors depends on the geometry of the sample and in this study is 100 mm. Determination of TOA (the exact time the event originated) is complicated where many data were recorded for each AE event. t_1 represents the time of arrival (or arrival of longitudinal wave, P-wave) at channel 1. Meanwhile t_2 is arrival of P-wave at channel 2. The arrival time difference between the arrivals of the signal at the two sensors can be written as

$$\Delta T = (t_1 - t_2) \qquad (4)$$

At selected source location, 10 times PLF were applied from the lower threshold level of 40 dB to the higher 70 dB. For ideal situation, the AE source location should be determined [6], where the sensors were used passively to detect AE signal and in this case the distance from sensors 1-2 and 2-3 is 0.1m and 0.2m, respectively.

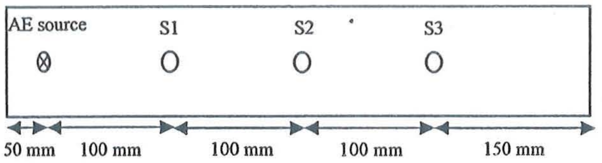

Fig. 1 The sensors set up on the RC beam specimen

TABLE II
SPECIFICATION AND FEATURE OF THE R6I SENSOR

Specification	Value
Dimension (Ø x height) mm	29 x 40
Weight (gm)	98
Operating temperature (0°c)	-45 to +85
Shock limit (g)	500
Peak sensitivity (V/m/s)	120
Directionality (dB)	+1.5

III. RESULT AND DISCUSSION

Typical AE burst waveform received by sensor R6I is shown in Fig. 2 from a reinforced concrete beam, represented in amplitude (v) against time (s). As lead breaks (in-plane or parallel to the sensors face) on the surface of the beam, a wave propagates through a solid medium; it carries certain amount of energy. The energy can be consumed by scattering during propagation. The scattering effect principally relies on the defects such as micro-cracks inside material. In wave velocity determination only several AE parameters would be considered such as time and amplitude. AE amplitude give the information about the time at which AE signals take place [8]. Wave velocity is one of the methods to be considered for source location.

In the test, gain 0 dB and preamplifier 40 dB were used with the sample interval of 10μs. In this case, the thresholds are assumed to be as lower as 40 dB (0.01V) to 70 dB (0.32V). Referring to eq. 1 and eq. 2, amplitude (represented in dB) can be calculated with the V_{ref} equals 1μv. Then volt for each threshold levels can be determined. Volt for each threshold can be used as a guideline for determining the TOA or P-wave at each sensor from AE source.

In this experiment, sensor 1 was set as individual due to close to the AE source and the rest were considered as synchronize. Thus, it can be clearly seen that the sensor 1 would be the first received the waves emitted by PLF at AE source followed by sensors 2 and 3 as depicted in Fig. 3, where the time of arrival or longitudinal wave (P-wave) for sensors 1, 2 and 3 were noted as t_1, t_2 and t_3 respectively.

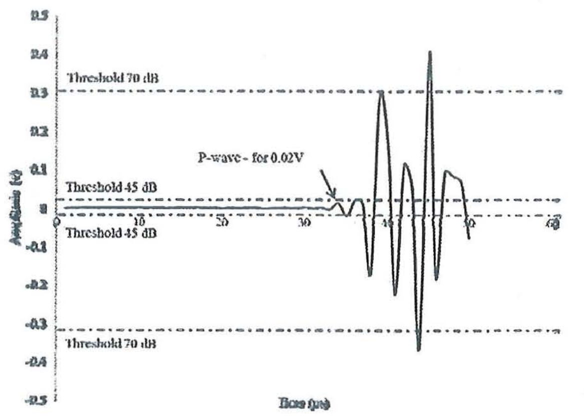

Fig. 2 Typical AE burst captured by R6I sensor

In determination of wave velocity, three threshold levels were considered; namely 45 dB, 65 dB and 70 dB. Fig. 4 is shown the wave velocity for three different threshold levels. It showed that the wave velocities are relied on the threshold levels, high threshold level would prolong the TOA of the wave, and thus the velocity would be reduced. At lower threshold (45 dB) and higher threshold (70 dB), the wave velocity was in the range of 2500 m/s to 4000 m/s and 2410 m/s to 3420 m/s, respectively.

However, the value was apparently lower compared to other researchers. For instance in heterogeneous material, Muhamad Bunnori et al. [3] stated that the wave velocity of RC beam (100 mm x 150 mm x 2000 mm) with the sensor distance of 250 mm, the value was in the range of 4000 m/s to 4500 m/s. Meanwhile Marrec et al. [9] reported about 2350 m/s for large spectrum with frequency between 50 to 600 kHz. Momon et al. [10] represented the wave velocity in ceramic matrix composite was 3200 m/s with the threshold level of 48 dB; however the initial velocity was 10000 m/s.

The wave velocity was also decreased as the distance increased due to attenuation of the AE signals. It means that the higher the distance from AE source, the smaller amplitude will be recorded, shows the ability of sensor to locate damage is limited [3]. From the observation carried out found that the wave velocity not only dependent to the thresholds but also the hit definition time (HDT) and hit lock out time (HLT) that have been set into the AEWin software prior to testing performed which relate to the amplitude and AE signals, where amplitude is affected by the travel distance of signals [8].

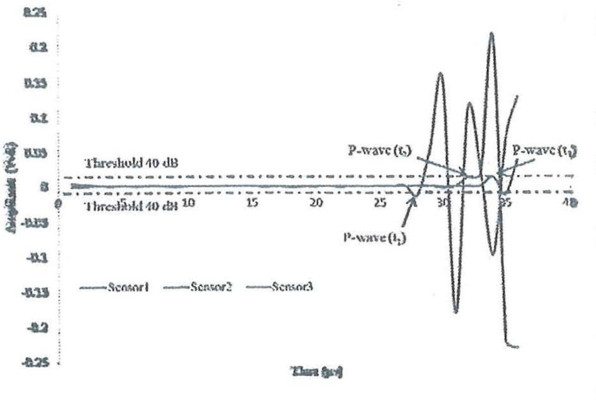

Fig. 3 TOA or P-wave for threshold 40 dB at time 18.8s for each sensor

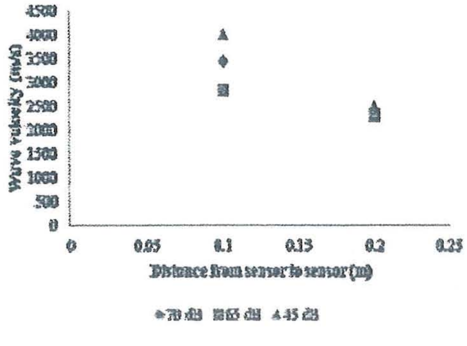

Fig. 4 Wave velocity for signal at threshold of 45 dB, 65 dB and 70 dB

IV. Conclusions

Three sensors were used for determining TOA and wave velocity in RC beam. Sensor 1 was set as individual due to close to the AE source and the first received the waves (P-Wave) were emitted by PLF in the solid medium of concrete followed by the rest sensors (set as synchronize). It can be concluded that the wave velocity was dependent to the threshold levels, high threshold level would prolong the TOA of the wave and the velocity would be reduced; which the wave travels in the RC beam at velocities in the range 2410 m/s to 4000 m/s. The wave velocity also decreased as the distance from individual sensor to synchronize sensors increased due to attenuation of the AE signals and smaller amplitudes were recorded.

Acknowledgment

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Overview of moment tensor analysis of acoustic emission signal in evaluation concrete structure

Shahidan, S.[a], Nor, N.Md.[b], Muhammad Bunnori, N.[a]
[a] School of Civil Engineering, Universiti Sains Malaysia (USM), Seri Ampangan, Seberang Perai Selatan, 14300 Nibong Tebal, Pulau Pinang, Malaysia
[b] Faculty of Civil Engineering, Universiti Teknologi MARA(UiTm), 13500 Permatang Pauh, Pulau Pinang, Malaysia

Abstract

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Index Keywords

Acoustic emission signal; AE analysis; concrete structure; Concrete structures; Crack classification; Crack volume; cracking; Moment Tensor Analysis; Quantitative information; Reinforced concrete structures; Research areas; Research papers
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Overview of Moment Tensor Analysis of Acoustic Emission Signal in Evaluation Concrete Structure

Shahiron Shahidan[#1], Noorshuhada Md Nor*[2], Norazura Muhamad Bunnori[#3]
[1,3]*School of Civil Engineering, Universiti Sains Malaysia (USM), Seri Ampangan, Seberang Perai Selatan*
14300 Nibong Tebal, Pulau Pinang, Malaysia
[#1]shahironshahidan@gmail.com
[#3]cenorazura@eng.usm.my

[*2]*Faculty of Civil Engineering, Universiti Teknologi MARA(Uitm)*
13500 Permatang Pauh, Pulau Pinang, Malaysia
[*2]idanur211@yahoo.com

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Keywords-component; Acoustic emission, Moment Tensor Analysis, concrete structure, cracking

I. Introduction

Worldwide, acoustic emission (AE) technique is well known and it is a powerful non-destructive testing for real time examination of the materials behaviour deforming under stress [1]. AE is the generation of transient waves due to rapid release of energy within a material, typically owing to the occurrence of damage. Although the technique has been successfully used for decades for damage detection and monitoring of concrete structure, comprehensive research particularly in the analysis has not yet been fully exploited.

Generally the AE analysis is relied on the signals that have received by the sensors. In analysing of AE signals, it can be divided into two main groups; classical (parameter based) and quantitative (signal based) [2]. Prior to signal based potentially demonstrated, parameter based is used for many researchers in analysis part of their research. Signal-based approach is not easily to analyse; where the waveforms recorded by sensors must be analysed and need practitioner or expert to analyse it. Due to the gap of research, this paper has reviewed one of the signal-based analyses known as moment tensor analysis (MTA) that still rarely used in damage detection analysis particularly for concrete structure. It can be used as a guideline or benchmark for newly researcher. Basically, Moment tensor analysis (MTA) is an AE post-test analysis method used to identify the crack kinematics, classification and volume from the recorded AE waveform [3]. Othsu has been developed the MTA technique since 1991 and improved to the new technique named Simplified Green's Function (SiGMA) by considering the first motions of AE amplitudes [4]. Currently, this technique also has been further investigated for geological background as well as rock deformations [5].

During the ancient time, the linear inversion techniques were proposed to determine the MTA in time and frequency domain. For instance, the technique is normally applied to obtain the stabilization solution in seismology and rock mechanics [6]. Currently, the applications of MTA in AE analysis are widely used in evaluation of concrete and steel structure. Referring to [7] has used MTA in concrete specimens failed in four-point bending. Results from analysis indicate that, the analysis can classify the shear and tensile crack and also the orientation of crack. Moreover the technique was formulated due to tensile motion of diagonal and shear motion of off-diagonal known as relative moment tensor inversion. The new technique is commonly present in crack motion during AE source [6]. According to [8], a moment tensor analysis is based on the measurement of P-wave amplitudes. AE waveforms are useful for quantitative evaluation of fractures in term of crack orientation, direction of crack motion and crack type.

Although, this technique has been applied to a variety of AE experiments in civil engineering, the application in concrete structure is still lack of attention and further study is needed.

II. Significant of Analysis

According to the performance of the structural concrete, the most popular concern about capabilities of concrete is the internal microcracking. This type of defect induced the less performance on the structural integrity particularly in concrete due to its characteristic of brittle material. In order to maintain the integrity, this type of cracking should be properly analysed and identified due to the characterizing of cracking in the concrete structure. Upon to that matter, MTA is useable to identify the cracking mechanism. Moreover, SiGMA – AE analysis is also consider as a sophisticated procedure for estimation the size, orientation, cracking classification, location and fracture mode of individual microcracking[9]. Furthermore, the SiGMA procedure also applicable and established for in situ concrete on estimation of cracking and degradation in concrete structure.

According to the [9] the SiGMA analysis also could lead for evaluation of cracking volume, which is applied to the AE waveforms data detected during the testing. Furthermore, SiGMA analysis also known in the process of concrete fracture that cracks of tensile type would be mainly obtained in early stage, then mixed-mode crack of tensile and shear type would follow and eventually the crack of shear type would be dominantly generated [10].

III. Theory

MTA is divided to three parts of evaluation analysis which are, crack kinematics, crack classification and volume. All these evaluation of analysis are determined by using AE-SiGMA. The SiGMA code was developed from elastic wave due to the microcrack nucleation in an isotropic and homogeneous.

A. Crack kinematic

The MTA equation has been generated from the theory of AE which is presented the AE wave due to cracking and formerly represented by [6].

$$U_k(X,t) = G_{kp,q}(X,y,t) * S(t)C_{pqij}n_jl_i\Delta V \quad (1)$$

However this formulation has been improved in response to initiation of cracks and become;

$$U_k(X,t) = \int_F C_{pqij}G_{kp,q}(X,Y,t) * [b(y)l_kS(t)n_1] = G_{kp,q}(x,y,t)m *_{pq} S(t) \quad (2)$$

From this mathematical formulation, the crack can be modelled by the crack motion vector *b* and normal vector *n* to the surface *F*, as depicted in Fig. 1. The motion of crack is already set as $b(y)lS(t)$, *Where;* $b(y)$ represents the magnitude crack displacement, *l* is crack motion direction vector, $S(t)$ is the source-time function, and from the formulation $G_{kp,q}$ is the spatial derivative of green's function.

For the surface crack *F* formulation due to moment tensor was presented by

$$\int_F C_{pqij}[b(y)l_kn_1] = [C_{pqij}l_kn_1]\left[\int_F b(y)dS\right] = [C_{pqij}l_kn_1]\Delta V = m_{pq} \quad (3)$$

In the case of an isotropic elasticity,

$$m_{pq} = (\lambda l_kn1\delta_{pq} + \mu l_pn_q + \mu l_qn_p)\Delta V \quad (4)$$

Where, μ and are lame constant and the summation convention is employed.

In Equation 1 the first motion A(x) of AE waveform are taking into account for solving the formulation.

$$A(x) = \frac{Cs}{RRef(s,r)r_pm_{pq}r_q} \quad (5)$$

Where *Cs* is the calibration coefficient, *R* is the distance, *r* is direction vector. *Ref (s,r)* is the reflection coefficient associated with the direction of sensor sensitivity *s* and direction of wave incidence *r* from the source as shown in Fig. 2. Then, the six components of Moment Tensor will be determined by solving the Equation. 4 at each observation point [9],[11].

B. Crack Classification.

The application of eigenvalue analysis is significantly important for classification of crack type. Generally, the type of crack will be classified into several modes, namely shear mode, tensile mode, and mixed mode. The eigenvalue decomposed into shear component X, hydrostatic component Z, and deviatric component Y, the three eigenvalues are normalized and composed into three ratios to determine the classification of the crack.

Thus the formulation of three eigenvalue presented below;

Maximum eigenvalue : $e_1/e_1 = X + Y + Z = 1.0$

Intermediate eigenvalue : $e_2/e_1 = 0 - 0.5Y + Z$

Minimum eigenvalue : $e_3/e_1 = -X - 0.5Y + Z \quad (6)$

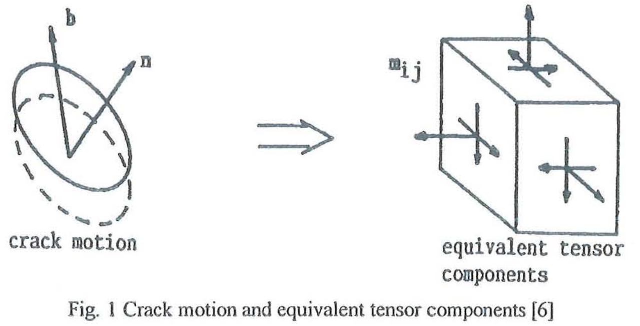

Fig. 1 Crack motion and equivalent tensor components [6]

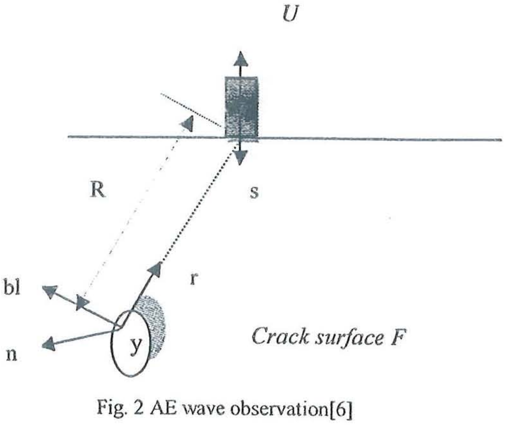

Fig. 2 AE wave observation[6]

From Fig. 3, e_1, e_2, and e_3 are the unit eigenvectors and correspond to the three eigen vector $l + n$, $l \times n$ and $l - n$, respectively [6],[9],[11]. In this case, the vector l and n are compatible [6] and represented in Equation 7.

$$l = \sqrt{2 + 2l_k n_k} \cdot e_1 + \sqrt{2 - 2l_k n_k} \cdot e_3$$
$$n = \sqrt{2 + 2l_k n_k} \cdot e_1 - \sqrt{2 - 2l_k n_k} \cdot e_3 \quad (7)$$

Under bending or tensile cracks the vectors l and n are parallel; however formerly in the first version of SIGMA found that l and n are perpendicular. Then, vector e_l is more closely to the direction of crack opening, while e_1+e_2 and e_1-e_3 derive the vectors l and n [6]. Referring to [10] light wave 3D software is functional for visualizing the cracking modes, such as tensile crack, mixed-mode and shear crack as presented in Fig.4. The figure was showed an arrow vector indicates a crack-motion vector and the circular plate are corresponds to the cracks surface which to perpendicular to a crack normal vector.

C. Crack volume

Crack volume determination is vital in moment tensor analysis in order to get clear picture on microcracking. In estimation of the micro-crack volume, the original magnitude of the moment tensor must be recovered. Mathematically, the moment tensor m_{pq} consists of the maximum component max (m) in the original moment tensor and relative moment tensor component m'_{pq} namely $m_{pq} = \max(m) . m'_{pq}$ and the Equation 5 is represented as;

$$\frac{A(x)R}{CsRef(s,r) r_p m_{pq} r_q} = m_{pq} = \max(m) . m'_{pq} \quad (8)$$

From Equation 5, the micro-crack volume in concrete structure can be determined [9].

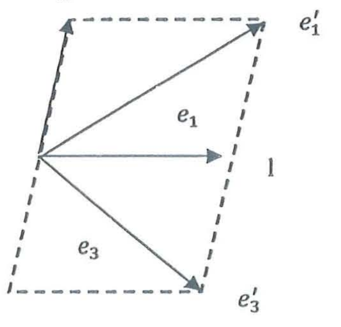

Fig. 3 crack orientation and eigenvectors

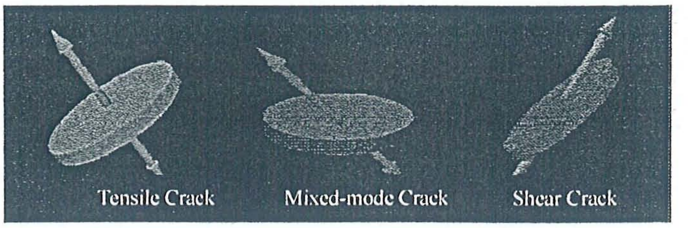

Fig 4 Display mode of Crack Classification [10]

IV. Case Studies

The application of MTA in AE Technique is very useful and effective in order to investigate the fracture mechanics in concrete structure. According to [9] the MTA is able to clarify and evaluate the micro-crack volume and damage parameter from moment component. This proved, when experimental work was carried out, which is in plane unconfined compression test of mortar and concrete plate with slit are tested by varies of inclination namely 0°, 30°, 45°. The result pointed that, the cement-mortar crack volume was larger than the concrete plate. This happened due to the coarse aggregate matrix bond are harder compared to cement -mortar. However, the results were similar to the damage parameter calculation, whereas the cement mortar value for parameter calculation was more prominent compared to the concrete plate. This correlation was proved that, the application of this analysis is applicable in evaluation of AE analysis technique.

In addition, the evaluations of AE source by utilizing the moment tensor have been published when the outcome from experimental work proved that, moment tensor analysis can clarify and identify the mechanism of cracking and the fracture zone [4]. Experimental work have been done by [10] regarding to the four point bending test of the normal concrete. According to that, AE event was determined the crack kinematics such as, crack types, orientation and crack classification as presented at Fig. 5. The result was indicated, a lot of tensile crack was observed at the bottom of the specimen and tensile crack are dominantly at final moment, as showed in Fig. 5.

Furthermore, referring to [12] indicated that, in order to localize the AE event and fracture mode accurately, MTA is the most suitable and effective approach for AE source analysis. Referring to[13] found that the analysis from the experimental work indicated that MTA is more efficient for interpretation and prediction of failure mode in composite structure. Apart from this orientation, volume and type of crack also can be estimated by utilizing this technique. This technique of analysis also can remark the large which cracks were classified as the tensile mode($X \leq 40\%$), mixed mode ($40\% \leq X \leq 60\%$) and shear crack ($X \leq 60\%$) [4],[6],[9]-[11].

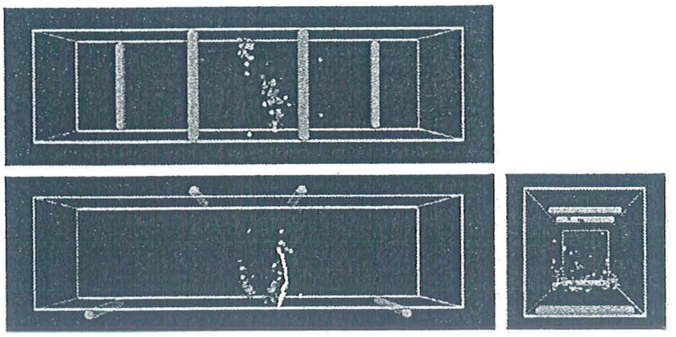

Fig. 5 Result of SiGMA analysis of four point bending test[10]

V. Conclusion

This paper has reviewed the significant and formulation of MTA in AE source for evaluation of damage mechanisms in concrete structure. Based on literature, two directions of crack vector and crack normal vector are determined exactly from this analysis procedure. This solution was confirmed that AE source was clustered close to the failure surface of concrete structure.

Furthermore, this procedure could give information on the crack mechanisms and orientation of fracture process. Thus, this type of analysis will able to use globally and greatly effective in determination of crack kinematic and source location of the damage mechanisms. Future research must be focused deeply on the analysing the real structure in their operational condition rather than laboratory tests of representative structures.

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An observation of noise intervention into acoustic emission signal on concrete structure

Nor, N.M.[a] ... , Muhammad Hussin, ... [a] ... [b] ...
[a] **Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM), 13500 Permatang Pauh, Pulau Pinang, Malaysia**
[b] **School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia (USM), Seri Ampangan, Seberang Perai Selatan, 14300 Nibong Tebal, Pulau Pinang, Malaysia**

Abstract

This paper is presented the observation of noise intervention into acoustic emission (AE) signal on reinforced concrete beam based on data recorded in the AEWin software at different pre-set thresholds manually. Two kinds of sources were selected; namely in-plane source and out-plane source. The correlation between threshold levels and number of hits has been observed. It can be concluded that for both AE sources in-plane and out-of-plane at the lower threshold level, huge hits were produced which including unwanted hits as well as noise. At high threshold level only required data / hits were recorded by AE signals, where the data presented owing to sudden release of stress from pencil lead fracture at selected source location. Thus, it produced lower correlation between threshold levels and a total number of hits recorded as the coefficient of determination for both sources is around 0.8 only and the graph produced is not linear. © 2011 IEEE.

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Acoustic emission; hits; in-plane; noise intervention; out of plane

Index Keywords

Acoustic emission signal; AE signals; Coefficient of determination; Concrete structures; hits, In-plane; Lower correlation; noise intervention; Out-of plane; Pencil leads; Reinforced concrete beams; Source location; Sudden release; Threshold levels
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An Observation of Noise Intervention into Acoustic Emission Signal on Concrete Structure

Noorsuhada Md Nor[#1], Norazura Muhamad Bunnori[*2], Azmi Ibrahim[#3], Shahiron Shahidan[*4], Soffian Noor Mat Saliah[#5]
[#]*Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM), 13500 Permatang Pauh, Pulau Pinang, Malaysia.*
[1]idanur211@yahoo.com
[3]azmii716@salam.uitm.edu.my
[5]pyan_noor@yahoo.com.sg

[*] *School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia (USM), Seri Ampangan, Seberang Perai Selatan, 14300 Nibong Tebal, Pulau Pinang, Malaysia.*
Address Including Country Name
[2]cenorazura@eng.usm.my
[4]shahironshahidan@gmail.com

***Abstract*— This paper is presented the observation of noise intervention into acoustic emission (AE) signal on reinforced concrete beam based on data recorded in the AEWin software at different pre-set thresholds manually. Two kinds of sources were selected; namely in-plane source and out-plane source. The correlation between threshold levels and number of hits has been observed. It can be concluded that for both AE sources in-plane and out of plane at the lower threshold level, huge hits were produced which including unwanted hits as well as noise. At high threshold level only required data / hits were recorded by AE signals, where the data presented owing to sudden release of stress from pencil lead fracture at selected source location. Thus, it produced lower correlation between threshold levels and a total number of hits recorded as the coefficient of determination for both sources is around 0.8 only and the graph produced is not linear.**

***Keywords*— Acoustic emission, noise intervention, hits, in-plane, out of plane.**

I. Introduction

Acoustic emission (AE) is a phenomenon of a transient stress waves resulting from a sudden release of elastic energy, caused by mechanical deformations, initiation and propagation of microcracks, dislocation movement, and other irreversible changes in material [1]. AE sensors are used to detect the acoustic waves at the surface of a structure, produced by AE events either on the surface or in the bulk of the material [2]. Basically, mode operation of stress wave detection is simple; when the stress waves reach the specimen surface the small displacements produced are detected by piezoelectric transducer, then the amplified signal is conditioned, recorded and analyzed [3].

On AE study, there are two methods normally used to analyze the output either by conventional or quantitative. Conventional method is easily to analyze due to parameter-based compared to quantitative method which based on the analyzing of the waveform or signal-based. There are two types of signals in AE system; namely burst and continuous signals. Burst signal is separate type of signals of a very short duration (in the range of a few microseconds (μs) to a few milliseconds (ms)) and the broad frequency domain spectrum. Meanwhile the continuous signal is emitted close to each other or the burst is very high rate where the signals occurred very close and sometimes even overlap. When the AE signal or output is transmitted in a structure, an array is identified. The output is always represented in waveform which has information on source location.

In the wave signal, noise is always presented leads to the unwanted data. According to Kalyanasundaram [4], AE testing is always accompanied by background noises which sometimes can completely submerge the AE signal. Elimination of the noises influence into signals is significantly vital for getting accurate data. There are different types of noises; for instance mechanical noise, hydraulic noise, cyclic noise, electro-magnetic noise and so forth.

This paper is presented the observation of noise intervention into acoustic emission signal on reinforced concrete beam based on data recorded in the AEWin software at different pre-set thresholds. Two kind of sources were selected; namely in-plane source and out of plane source. Previously, very little attention has been paid for noise intervention based on data recorded in the AE software and the consideration of shorter distance of source – to – sensor distance.

II. Experimental Procedure

A. Preparation of Beam Specimen

The concrete beam was prepared for concrete strength of 40 N/mm^2. The beam was made up of cement, fine aggregate, coarse aggregate and water by weight with the proportion of 1:2:2.9:0.57, respectively; then cured in water tank for 28 days. In this research, the maximum size of aggregate was used is 20 mm. The size of the beam is 100 mm width, 100 mm thick and 500 mm length. Two high strength steel bars were embedded in the concrete from 20 mm of the bottom edge of the concrete; to strengthen the tension part would be used for flexural test later that would not mentioned here. Two 6 mm diameter of mild steel bars were used as hanger bars and stirrups.

B. Acoustic Emission System

Acoustic emission (AE) was monitored using a MicroSAMOS (μSAMOS) supplied by Physical Acoustic Corporation (PAC). The system consists of integral preamplifier acoustic emission sensors (transducers) R6I (40 – 100 kHz); a notebook acoustic emission system board (8 (channels) x 16 (hubs) bit acoustic emission channels, low peak and high peak filters, 2 MHz bandwidth, auto sensor test (AST), time definition display (TDD), digital signal processor (DSP) and waveform module; personal computer memory card international association (PCMCIA) interface card; cables; internal and external parametric cable set; a notebook personal computer with full suite of AEWin Software; universal serial bus (USB) license key; and magnetic clamps. The acquisition parameters in the AEWin software were summarized in Table 1.

TABLE I
AE TEST PARAMETERS

Parameter	Value
Hit definition time (HDT)	2000μs
Peak definition time (PDT)	1000μs
Hit lockout time (HLT)	500μs
Threshold	45dB
Preamplifier (R6I)	40dB
Bandpass data acquisition filter	400kHz
Sample rate	100ksps
Analog filter (lower)	1kHz
Gain	0dB
Pre-trigger	250,000
Waveform set up length	1k

C. Noise Observation

Prior to any test carried out, three pair thin plates were prepared to attach the sensors S1, S2 and S3 with the specific distance between pair of plates of 45 mm. The beam surface where the sensors attached was grinded smoothly to ensure good connectivity between sensors and beam surface. The plates were then fixed to the beam surface using epoxy and hardener. To ensure the sensors coupled to the specimen, a thin layer of grease (couplant) was applied between sensors and the specimen surfaces. The couplant aids the transmission of acoustic waves between two surfaces (sensor surface and beam surface), while a bond is a couplant which physically holds the sensor to the specimen surface [5]. The magnetic clamps were used to safeguard the sensors; which sensors held in position in magnetic clamps; then the magnetic clamps properly griped to the steel plates. In this experimental work, three R6I sensors with 50 kHz resonant frequency were used. Acoustic emission sensors are transducers that convert the mechanical waves into electrical signal, where the information about the existence and location of possible damage or stress released sources can be obtained. The specification and feature of the sensor is shown in Table 2.

In determination of noise intervention in wave signal no significant calculation is needed. The data can be calculated manually for each pre-set threshold level. A schematic diagram of the test set up in a linear structure is shown in Figs. 1 and 2. The AE sources were identified on the in-plane and out of plane of the arrangement of the sensors. Three sensors were used with the same spacing of 100 mm centre to centre. Prior to test, calibration check was carried out as well as the sensitivity using a Hsu-Nielsen technique at each sensor. This is to verify that each sensor remained fixed to the specimen to give adequate result. During experimental, the major drawback arose was sensitivity checking where the amplitude must be at least within + 3 dB in different. Sometimes this part would take about more than half an hour.

The more sensors used, the more time would be considered. In order to overcome the problem several ways has to be considered as well as the sensor in the magnetic clamp must be properly position (tissue paper was used around the sensor in the magnetic clamp to tight them), enough couplant was applied on the sensor surface and beam surface and properly handled the pencil lead fracture (PLF) (in good technique as recommended in the standard).

TABLE II
SPECIFICATION AND FEATURE OF THE R6I SENSOR

Specification	Value
Dimension (Ø x height) mm	29 x 40
Weight (gm)	98
Operating temperature (0°c)	-45 to +85
Shock limit (g)	500
Peak sensitivity (V/m/s)	120
Directionality (dB)	+1.5

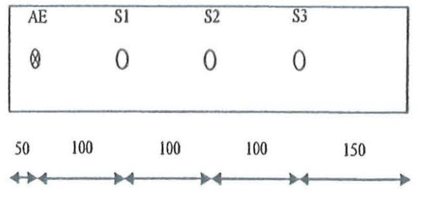

Fig. 1 The sensors arrangements for in-plane (plan-view)

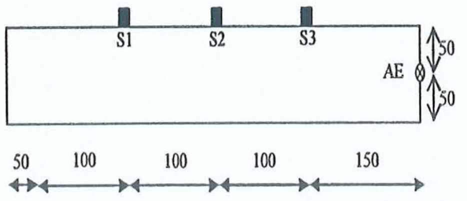

Fig. 2 Measurement arrangements for out-plane

Note: dimension in mm.

This paper is presented a part of study of wave velocity in concrete structure regarding to noise and its correlation to the pre-set threshold levels. The data provided was taken out from wave velocity test in form of hits. To generate the wave velocity, for in-plane measurement PLF was carefully performed at 100 mm from sensor 1 known as Hsu-Nielsen or artificial AE source. For out of plane measurement, the sensor is located at the edge of the beam as shown in Fig. 2. For both AE sources in-plane and out of plane, when the lead breaks, the stress on the surface of the specimen where the lead is touching is suddenly released. It is important to handle the pencil properly during broken the lead against the testing specimen to get significant results. From experience in experimental showed that wrong handle of the pencil will give imprecise value; which affect to the time of arrival (TOA). At selection source location, 10 times lead breaks were applied from the lower threshold level of 30 dB to the higher 70 dB. Then the data (hits) recorded were observed.

III. Results and Discussion

Typical waveform received by sensors is shown in Fig. 3, represented in voltage (mv) against time (μs). The sensor has a resonant frequency of 50 kHz which response to plane waves.

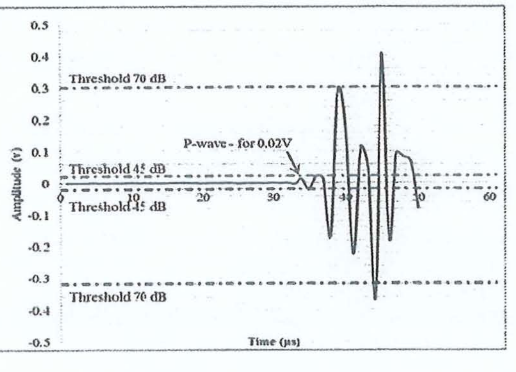

Fig. 3 Waveforms captured by R6I sensor

Table 3 represented the various pre-set threshold levels and the total number of recorded for three sensors. In this case, the thresholds were pre-set to be as lower as 30 dB to 70 dB. In each threshold level, 10 times PLF were applied for in-plane and out of plane sources. Each PLF would produce one event; where event is a local material change giving rise to AE [1]. An AE signal on an individual sensor channel from one event defined as hit. A single event can result in multiple hits [6]. For each hit for both sources the number of data points per waveform is 1024.

The observation of number of hit data set (HDS) recorded during testing is significantly vital for more understanding on the presentation of noise in the wave signal. It can be observed visually or simply calculate the HDS recorded in the AEWin system. At lowest threshold of 30 dB the noise can be clearly seen from the data recorded, where in-plane measurement the total HDS reported during testing was 198, means each sensor has given 66 hits. It showed that 188 HDS was noises due to the fact that signal and noise of AE in concrete are often to be the same frequency range of 20 kHz up to 300 kHz [7].

Meanwhile for out of plane, huge number of HDS was recorded of 240. In these cases, not all hits were significantly required for wave velocity or damage determination. Due to disturbance of noise into the signal wave could not be filtered out at lowest threshold. At this threshold level, all the low and high signals due to sudden release of stress triggered from PLF and noise signal from outside of the sensors array would be recorded. It would affect to the AE data required.

However, the higher the threshold set into the software, the lower noise could be filtered out and more accurate data will be recorded. For instance, at threshold 70 dB for both sources in-plane and out of plane the number of hits was 30, means each sensor recorded 10 hits. It showed that the number of PLF propagated the sudden release of stress on the surface of the specimen where the lead is breaking, seemingly at this threshold level all the noise was filtered out. One of the disadvantages of applying higher noise level is the lower signals cannot be detected.

TABLE III
AE Sources Hits for Different Threshold Levels

Threshold (dB)	No. of hits data set	
	In-plane	Out of plane
30	198	240
40	78	99
45	75	72
50	66	33
60	36	33
70	30	30

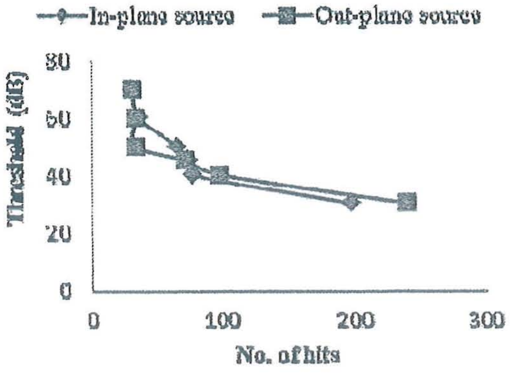

Fig. 4 Threshold levels versus number of hits

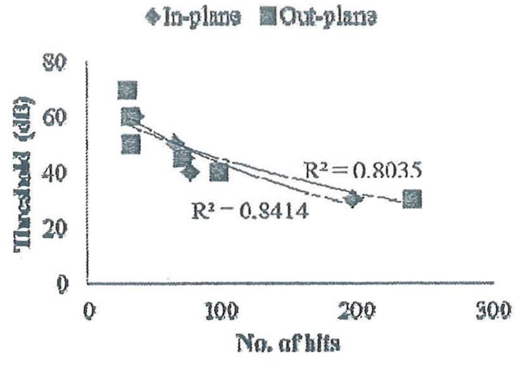

Fig. 5 Correlation between threshold levels and number of hits

Graph of threshold level and number of hits is depicted in Figure 4. For lower threshold, noise signal from outside the coverage zone of the sensor array would be influenced the hits recorded. The coefficient of determination, R^2 was used in the prediction of future relationship between threshold and data as shown in Figure 5. It is clearly can be seen that the relationship between threshold and number of data is not linear with the R^2 for in-plane and out-plane is 0.8414 and 0.8035, respectively. Thus, the linear regression is not perfect between threshold levels and number of data produced by AE signals; which produced lower correlation.

IV. Conclusion

It can be concluded that for both AE sources in-plane and out of plane at the lower threshold level huge hits were produced which including unwanted hits as well as noise. At high threshold level only required hits were recorded by AE signals, where the hits presented owing to sudden release of stress from lead was breaking at selected source location. Thus, it produced lower correlation between threshold levels and total number of hits recorded as the coefficient of determination for both sources is around 0.8 only and the graph is not linear.

Therefore, it is possible to reduce the noise by using filters, reducing gain or increasing the threshold. However, at lower threshold, it would effect to the AE data where some of the low amplitude AE signals cannot be detected. Kalyanasundaram et al. [4] stated two method to eliminate the noise either using spatial filtering or parametric filtering. This is good approach for future study based on AE signals which relate to noise elimination.

Acknowledgment

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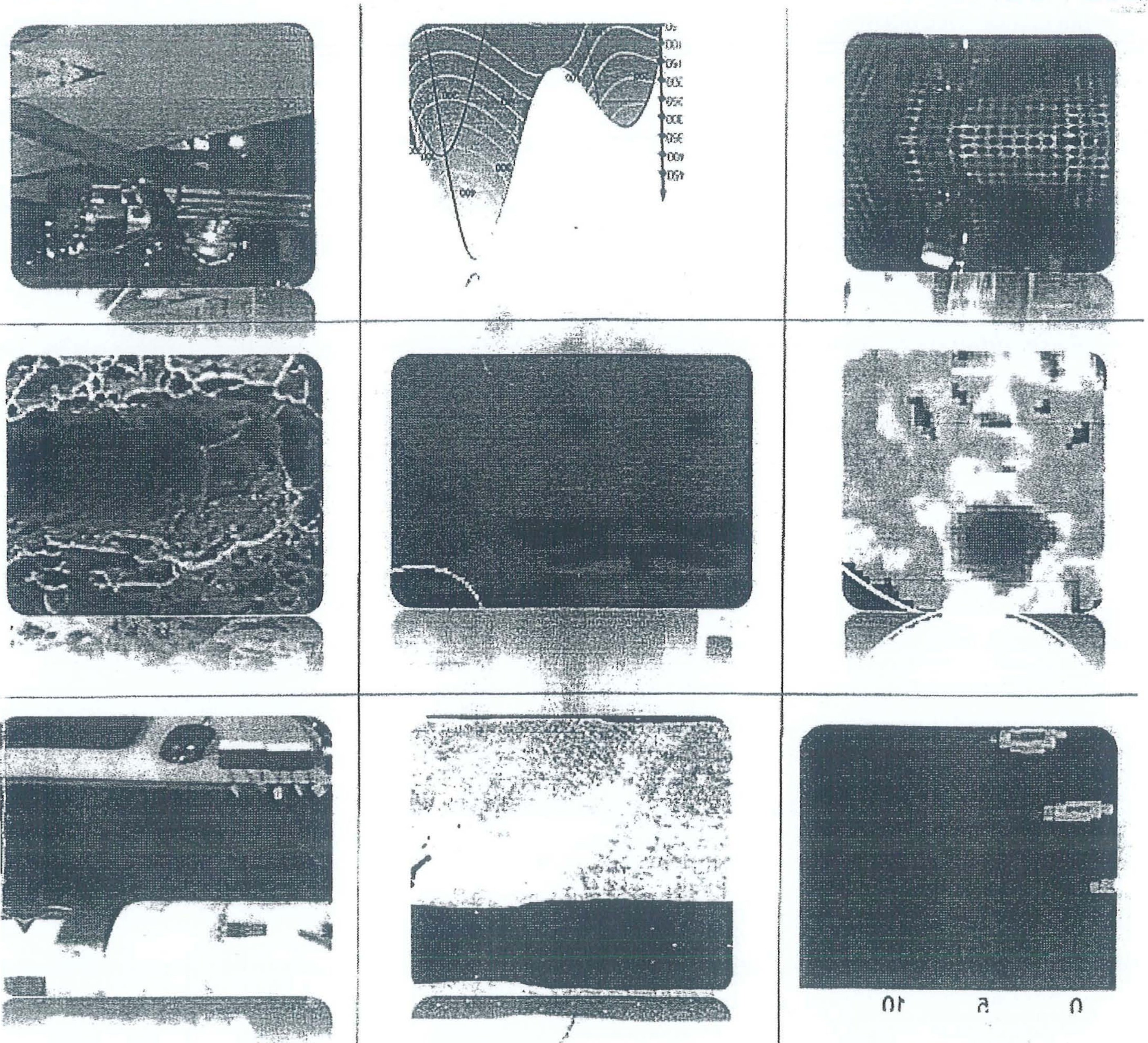

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GLOBAL MONITORING OF REINFORCED CONCRETE BEAM USING ACOUSTIC EMISSION TECHNIQUE

Sakhiah Abdul Kudus, Fairuz Wahida Zulkefli, Norazura Muhamad Bunnori

School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, 14300, Nibong Tebal, Penang, MALAYSIA.
Tel: 04-5995999 Fax: 04-5941009

sakhiah88@ymail.com, fairuz_wahidah88@yahoo.com, cenorazura@eng.usm.my

Keywords: Acoustic emission, cracks location, structural damage

Abstract: *This paper describes an experimental programme to investigate the structural damage assessment by using AE for concrete structure. In this analysis, the AE technique is used to analyze the structural condition of a concrete beam located in Concrete Laboratory, School of Civil Engineering, Universiti Sains Malaysia. The objective is to investigate the AE technique for use in structural health monitoring monitor the cracking which has developed on the structure and to identify the location of the active crack. Acoustic Emission (AE) technique is a dynamic Nondestructive Testing Technique (NDT) which the signal is coming directly from the damage area. Each defect produced its own emission which can be evaluated by using AE technique. A parameter-based approach was used to analyse the data acquired by the AE instrumentation. This approach evaluates relative AE activity based on the measurement of parameters such as hits, amplitudes and absolute energy. This method of analysis has been shown to be sensitive to the initiation and growth of cracks within both homogeneous and composite materials and structures. It is also shown that the application of a linear location, Time of Arrival (TOA) method can be used to determine the location of damage in an area between an array of sensors and to monitor the progression of the resultant cracking. Visual observation was done in order to compare the result obtain from the AE technique. The result show that AE technique has a promising accuracy in located the position of cracks. The results prove that AE technique has the ability to detect, locate and monitor the crack at the concrete beam in concrete lab.*

Introductions

Most of the developed infrastructures in the world are built using concrete. Concrete structures are usually adequately durable for their planned use, but sometimes deteriorate prematurely. So it is important to identify deterioration early. The deterioration of civil infrastructure worldwide calls for effective methods for damage evaluation and repair. One of them, the acoustic emission (AE) monitoring technique, uses signals generated within the structure, which are due to crack growth under stress, to parameterize the fracture/failure process, as well as secondary emissions due to friction of crack interfaces [1].

The most important applications of AE to structural concrete elements started in the late 1970s, when the original technology developed for metals was modified to suit heterogeneous materials [2, 3].

This unique monitoring mechanism distinguishes the technique from other nondestructive testing methods and makes it the only one capable of real time mapping of fracture processes. In addition to real time source location of the captured AE events, the energy level or magnitude of the detected events, offers an evidence of the degree of damage provided that other sources of noise are excluded [1]. When structural damage occurs, a spontaneous release of strain energy creates transient stress waves known as acoustic emission (AE), which propagate through the material. The acoustic emission technique is applied to identify defects and damage in reinforced concrete structures and masonry buildings [4]. This technique permits to estimate the amount of energy released during fracture propagation and to obtain information on the critically of the ongoing process. In addition, based on fracture mechanics concepts, a fractal or multistage methodology is proposed to predict the damage evolution and the time to structural collapse. A particular engineering advantage of the AE technique is its efficiency for global monitoring as a large and complex structure can be monitored with a limited number of sensors [5].

The current state of concrete lab structure in the School of Civil Engineering, Universiti Sains Malaysia (USM) needs a continuous structural monitoring appraisal. The passive nature of the acoustic emission (AE) evaluation technique makes it an ideal choice to serve this purpose.

The objectives of this experiment are to examine the condition of the structural damage using acoustic emission techniques as a non-destructive testing (NDT) technique for reinforced concrete structures, to monitor the cracking and to determine the location of the active cracks which has developed on the structure. The work focuses on the data analysis methods using AEwin software for the detection of active crack at the structure.

AE Test Methodology

The research is focused on the global monitoring. This test is carried out at the Concrete Laboratory, School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia. Two reinforced concrete beams have been monitored. The first one is located at near the entrance of the concrete laboratory. The second beam is located at the connection between existing building and the new building. Both of the beams are come from the additional building of the concrete laboratory that was built on 2005 which is connected to the existing concrete laboratory building. The AE technique has been applied on the beam in order to evaluate the status of the existing cracks.

In AE monitoring, a total of 8 sensors were attached to the surface for each beam using R6I sensor. They were placed on longitudinal axis of the beam. The locations of the sensors for each beam are shown in Fig. 1 and Fig. 2. An essential requirement in mounting a sensor is sufficient acoustic coupling between the sensor face and the structure surface.

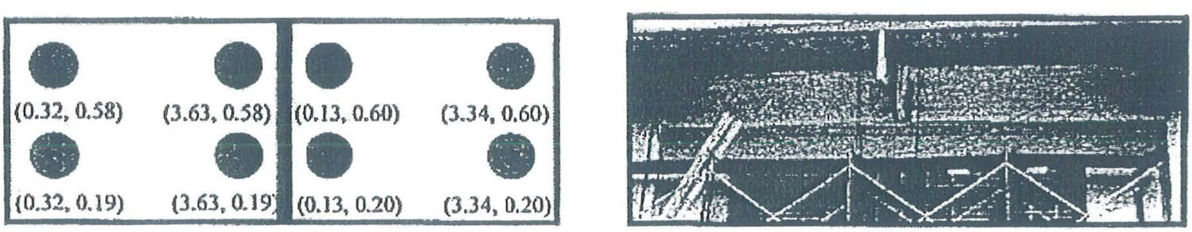
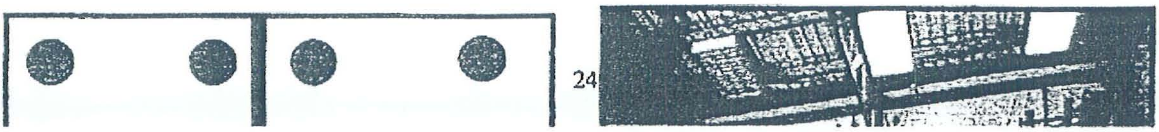


Fig. 1 Coordination of each sensor for beam 1 in X axis and Y axis (unit: meter)



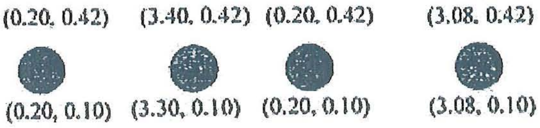


Fig. 2 Coordination of each sensor for beam 2 in X axis and Y axis (unit: meter)

AEwin for micro-SAMOS is the windows based AE acquisition, analysis and replay software program provided with the micro-SAMOS and PCI-8 based systems.

Prior to the monitoring, a full AE structural calibration was carried out on the beam by using two sensors. This calibration comprised of the following test [6]:

1. Attenuation Survey – Signal attenuation was found to be low (30dB signal loss over 3m) for concrete with pencil break signals readily detected at a distance of 3m from the sensor.
2. Back Ground Noise Check – The environmental noise check established that a comparatively low threshold of 40 dB could be used.
3. Wave Speed Check – The wave speed was calculated as 3455m/s, which was entered into the AE system software to allow accurate location of sources.

The structure has been continuously monitored for 2 days, corresponding to 48 hours.

Result and Discussion

The test focuses on the monitoring and identified the cracks whether the cracks on the beam are active or not. It was suspected that the beam undergoing active cracks. From the result of the monitoring, AE method is useful in determine the growth of the micro cracking at the critical area of the structure. A comparison between the visual observations of the cracking location and AE source location analysis indicates the area of the cracking, which can be identified by the AE source location.

Detection of emission from growing cracks has been the most common goal in the many applications of AE technology. When a surface-breaking crack grows, the structure opens up in response to the applied forces. This is far more serious than the opening of an inclusion, which would tend to have no more than a local effect. Therefore, cracks tend to produce higher amplitude signals that are more readily detectable.

Data Location Display

In this experiment, the typical location display is computed. One of the data location display is a graph of Absolute Energy versus X position. When linear location is being used, the data display is a histogram with the span between the sensors laid out along the X axis. The highest peak shown there have the majority of the emission activity originates.

Results for Beam 1

In Beam 1, channel 7 and 8 detects the highest reading which was 1.59×10^4 aJ as shown in Fig. 3. The absolute energy increased dramatically at the position 1.6 meters as illustrated in Fig. 3 where the cracks already formed. From the observation, a wider crack has been observed at this position and downward propagation had occurred. The high level of absolute energy were suspected be due to the propagation of the crack.

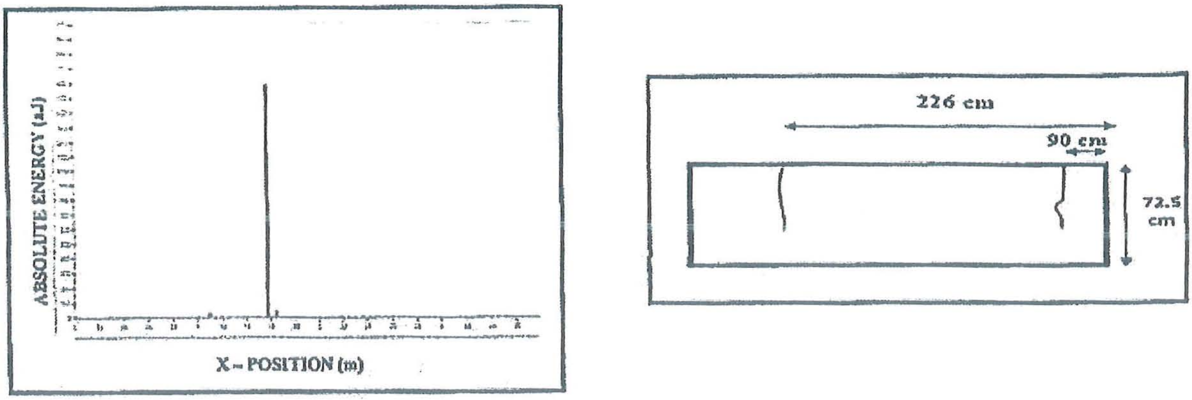


Fig.3 The location of cracks between channel 7 and 8

Fig. 4 shows the comparison of the crack location in between channel 5 and channel 6 from AEwin software and visual observation. By visual observation, the cracks were observed visually on beam surfaces at approximately 1.2 m. In AEwin software, the cracks were occurred at 1.7 m. The result is slightly different sine the crack did not propagate totally vertical. Based on the visual observation, it shows three hair line cracks had been observed. From the AE result it shows that the value of absolute energy at channel 6 is very high which 6.58×10^7aJ is. Channel 5 and 6 located at the top of right hand side of the beam. The high value of the cumulative absolute energy located approximately at the 3.35 meter. Due to high energy had been detected, it believe that the emission came from the three hair line cracks that newly developed. A further investigation is needed for a future study.

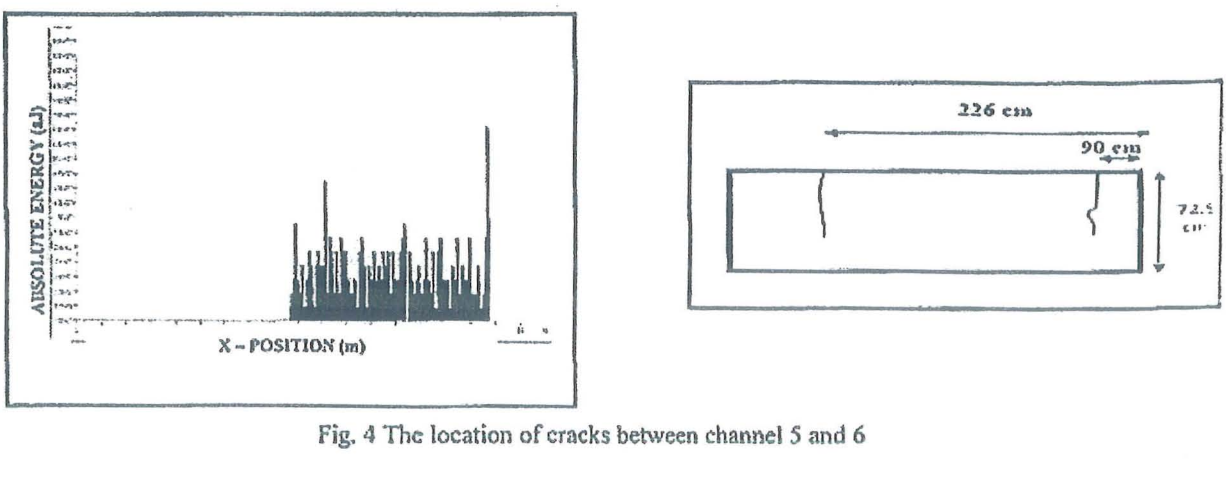


Fig. 4 The location of cracks between channel 5 and 6

Results for Beam 2

Fig. 5 shows the linear location of the crack from the AEwin software and the actual location of the crack on the beam between the sensors 7 and 8. The sensor 7 and 8 located at the bottom of right hand side of the beam. The high value of the cumulative absolute energy located approximately at the 1.5 meter to 1.6 meter. The highest peak of graph is around 2.23×10^4 aJ. These show that there is only involved an opening and closing of the same exists cracks. From the visual observation, the massive crack located approximately 1.6 meter which is the same location as AEwin result shows.

Fig. 6 shows the location of the crack between the sensor 5 and 6 on the real beam and the location from the AEwin result. The actual location of the crack on beam is same as the crack located at between the sensor 7 and sensor 8. The higher energy recorded is 1.65 x 10^3 aJ. The small energy *indicated the opening and closing of the existing cracks.*

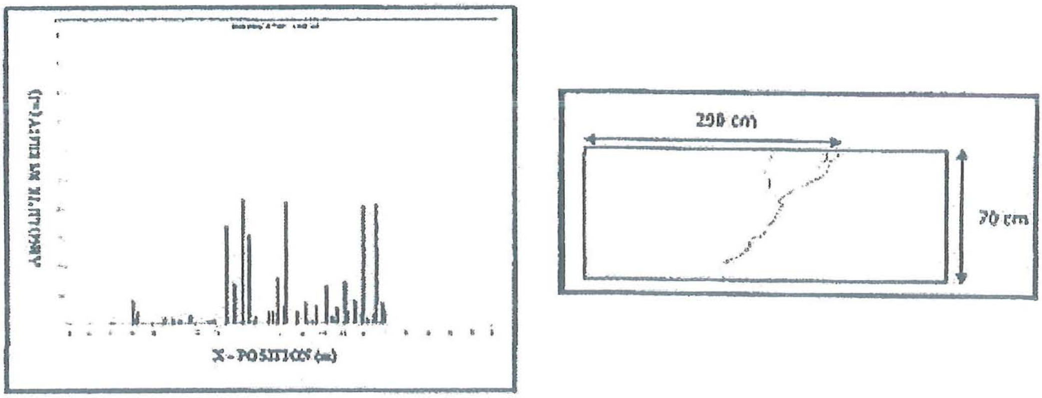


Fig. 5 The location of cracks between Channel 7 and 8

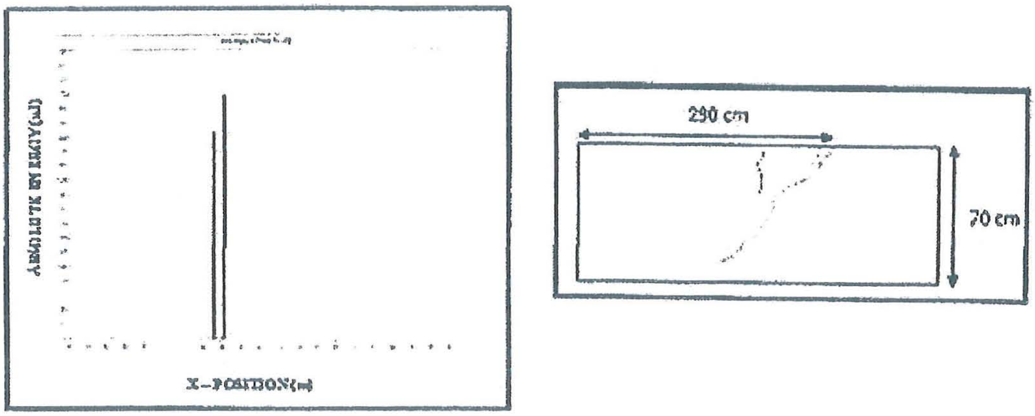


Fig. 6 The location of cracks between Channel 5 and 6

This study had investigated and compared the results from visual observation and the results from AE system. Two reinforced concrete beams have been monitored and it shown that the patterns of emission were almost the same. Based on the results of monitoring in 48 hours, it has been identified that the AE method can be used to determine the active crack and the location of crack. In addition, a comparison between visual observations of the crack location and results from AE system can be clearly identified. Moreover, the capability of the AE technique to monitor structural behavior in concrete is promising.

Conclusion

In this test work describe the application of the AE technique to monitor the structure. The conditions of stability or the risk due to the spreading of cracks are based on the counting of hits in order to determine the released energy.
By monitoring the evaluation of damage by means of the AE technique, it is therefore possible to evaluate the damage level for the structure. AE allow to ascertain stability or instability condition and to forecast the extent of damage in the structure by propagation of the cracks. The results obtained from the monitoring seem to indicate that the monitored region has no real issue with their structural

integrity. Continue efforts show that the technique has promising future in becoming an integral part of any structural health monitoring system.

Thus, from the absolute energy information can conclude that the monitored region had no serious structural damage except for opening and closing of the existing cracks. Monitoring of the building due settlement process give a very low emission to AE system as compared to monitoring bridge which experienced a continuous dynamic loading from the vehicle.

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Damage Severity Evaluation on Reinforced Concrete Beam by means of Acoustic Emission Signal and Intensity Analysis

Shahiron Shahidan[#1], Norazura Muhamad Bunnori[#2], Noorshuhada Md Nor[*3], Siti Ramziah Basri [#4]
[1,2,4]*School of Civil Engineering, Universiti Sains Malaysia (USM), Seri Ampangan, Seberang Perai Selatan*
14300 Nibong Tebal, Pulau Pinang, Malaysia
[#1]shahironshahidan@gmail.com
[#2]cenorazura@eng.usm.my

[*3]*Faculty of Civil Engineering, Universiti Teknologi MARA(Uitm)*
13500 Permatang Pauh, Pulau Pinang, Malaysia
[*3]idanur211@yahoo.com

Abstract— **Concretes structures have been facing several types of damage mechanisms during their lifetime. The types of common defects in concretes structures are crack formations, corrosion, scalling, and etc. Therefore, an evaluation method such as acoustic emission (AE) is required for assessing the deterioration on concretes structures. This paper provides a brief discussion on the evaluations of the acoustic emission signal strength to the health monitoring of reinforced concrete structures beams. Small scale size beam has been used for this investigation and the AE signal processing is the main principal data in this work for assessing by using the statistical quantitative technique, which is known as intensity analysis (IA).This type of technique is able to quantify and evaluate the damage severity on concretes structures. Eventually, the results presented in this research using AE signal strength are greater parameter in determining the micro and macro cracking and also the damage mechanism level on concretes structures.**

Keywords; Acoustic emission Signal, Intensity analysis, cracking, Quantitative method

I. Introduction

In universal, the applications of reinforced concretes structures have been used in the world since ancient time. Basically, it was commonly applied in buildings, bridges, highways, foundation, dam, airport etc. Even nowadays, the popularity of the reinforced concretes structures applications has been maintained in a major and minor construction.

Regarding to that matters, it has been facing several types of damage mechanism and deterioration during service. In such deteriorations are the high loading of structure due to the increasing traffic flow and severe environmental effects such as, scaling, spalling and corrosion. Therefore the process of the damage mechanism on concretes structures will be induced the interaction of the duration between long term and short term processes. However these interaction times of the process affected the condition and performance of the structure. There are commonly occurring on the aging buildings and the structure bridges. Crack formations are commonly the types of defects in concretes structures. The crack formations in the concrete materials are often at the origin of serious damage due to corrosion [1]. Basically the crack growth formation in concrete material is mainly divided by two major parts, which are micro cracking and macro cracking. These types of mechanism are normally occurred due to the mechanical interaction, high stress level, fracture energy and strain softening. These types of defects are highly needed in order to inspect and monitor the structure for the reliability and integrity.

In order to maintain the structural integrity and monitor the defects in the concrete structure, nondestructive testing (NDT) is an effective method for the investigation and evaluation of the actual condition of concretes structures [2]. One of the excellent techniques in the various types of NDT methods is Acoustic Emission (AE). Today, AE is found to be the most efficient and powerful NDT for real time testing of the materials behavior deforming under stress [3].The technique has been successfully used for decades as damage detection and monitoring of concrete structure[1- 4].

The aim of this paper is to assess and evaluate the AE signal strength due to the loading condition based on the Intensity Analysis (IA) method. The first part of this paper is mainly discusses the fundamental of AE covering the principle of AE. Next, brief the review of IA method, followed by experimental work including the result and discussion and eventually the conclusion of the investigation.

II. Fundamental of AE

Basically, AE was generated when a solid object is subjected to the stress level. The term of AE is from the phenomena of sound generation in material under certain level of stress. This phenomenon has also been known and referred to as stress wave emission. According to [5] formally defines AE as the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from localized source with a material or transient wave so generate.

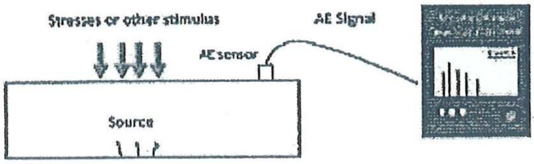

Fig. 1 Acoustic Emission technique diagram

AE can also be defined as the stress waves produced by sudden movement in stressed materials. The classic sources of AE are defect related deformation processes such as crack growth and plastic deformation [6,7].

The principle of AE process of generation and detection is illustrated in Fig. 1.When a structure is subjected to an external stimulus which means change in pressure, load, or temperature, the energy of localized sources will be released in the form of stress waves, which propagate to the surface and recorded by sensors as shown in Fig 1. As the stress in the material is raised, the emissions of wave are highly generated.

Applications of AE technique have been used for many years and were established as powerful tool in monitoring techniques [6-10].

In addition, the most recent information is, AE technique is capable to analyze the damage and failure mechanisms of a multifilament yarn embedded in concrete during a pull out test and also capable of revealing damage processes in material during the entire load history [11-13].

In measurement system, AE signal analysis can be categorized by two divisions as qualitative and quantitative methods. In the following topic, quantitative method has been proposed and discussed for damage quantification.

III. INTENSITY ANALYSIS

Intensity analysis (IA) is the technique that evaluates the structural significance of an AE event as well the level of deterioration of a structure by calculating two values which are called Historic Index (HI) and Severity (S_r) [14]. Referring to [3], this quantification method known as the statistical analysis and has been successfully utilized to FRP and metal for evaluation system.

The indices are calculated using the following formulas [3,14 -17] :

$$H(I) = \frac{N}{N-K} \cdot \left(\frac{\sum_{i=K+1}^{N} S_{oi}}{\sum_{i=1}^{N} S_{oi}} \right) \quad (1)$$

$$S_r = \frac{1}{J} \cdot \left(\sum_{m=1}^{J} S_{om} \right) \quad (2)$$

Where as, $H(I)$ = Historic Index, N = Number of hits up to time t, S_{oi} = Signal strength of the ith hit, K = Empirically derived constant based on material, S_r = Severity index, J = Empirically derived constant based on material, S_{om} = signal strength of the mth hit where the order of m is based on magnitude of the signal strength. For concrete, K and J value are related to N by the relations: $K = 0$, $N \leq 50$; $K = N - 30$, $51 \leq N \leq 200$; $K = 0.85N$, $201 \leq N \leq 500$ and $J = 0$, $N < 50$; $J = 50$, $J \geq 50$.

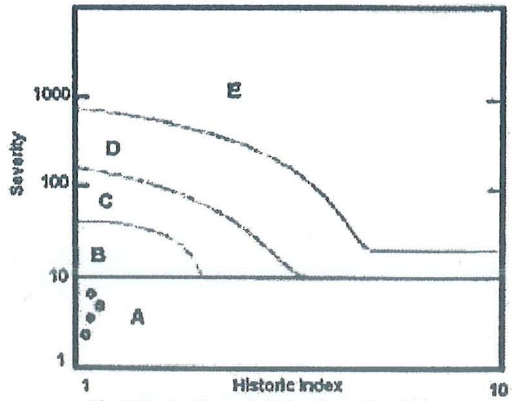

Fig. 2 Typical intensity chart for bridge[15]

This method is evaluated from the AE signal strength data collected by the AE win software by each sensor. Therefore the severity and maximum historical index will be plotted on the intensity chart as presented in Fig. 2.

The chart is divided into five intensity zones, which indicate the structural significance of the emission. All the zones description was presented in table 1. According to the chart, the high structure values for intensity analysis will plot toward the top right hand over of the chart, while the values of less significant are in the bottom area and normally in the left hand of the chart.

IV. LABORATORY WORK

Only three concrete beams small scale size, cross section 100 mm X 100mm and length 500mm were included in this investigation and tested by three point bending together with the AE sensor monitoring as shown in the Fig. 3. It was reinforced with high tensile strength size T10 and the steel bar was hanger with mild tensile strength of 8mm, while as

TABLE 1 Significance of intensity zones [16]

Zone Intensity	Recommended action
A	Insignificant acoustic emission
B	Note for reference in future tests. Typically minor surface defects such as corrosion, pitting, gouges or crack attachments welds.
C	Defects require follow-up evaluation. Evaluation may be based on further data analysis or complementary ondestructive examination.
D	Significant defect requires follow-up inspection.
E	Major defect requires immediate shut-down and follow-up inspection

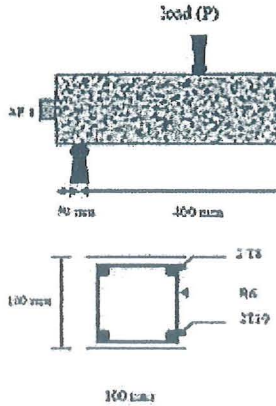

Fig. 3 Testing procedure and detail dimension

for the size of stirrups are R6 that normally use in the small scale size. In this study, the target design strength of concrete was 30MPa for 28 days.

During the testing, AE signals were recorded by two channel (R6I) Physical Acoustic Corporation (PAC) measurement system. The two sensors were located on the side face (Channel 1 and Channel 2) and the setting threshold was 45dB for eliminate noise of the surrounding area. The signals that were received by the sensor were collected, stored and processed in the data acquisition system. In this testing, the stepwise loadings have been selected and applied starting from 0.5KN up to the failure as presented in Fig. 4. Between each of the stepwise loading, it was kept constant for 3 minutes prior to the next step loading till the failure stage. The entire loadings for this work were applied by hydraulics jacks and the pressure was controlled with a manual oil pump for each step loading.

V. Result and Discussion

This section presents the AE result analysis and observation that were obtained from the three beams tested in the laboratory. The first part of this section describes the result analysis from the three point bending test by applying of stepwise loading as shown in Fig. 4. Then, the descriptions on the outcomes of the IA were presented in the AE signal strength data.

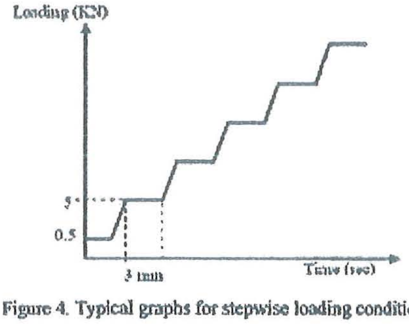

Figure 4. Typical graphs for stepwise loading condition

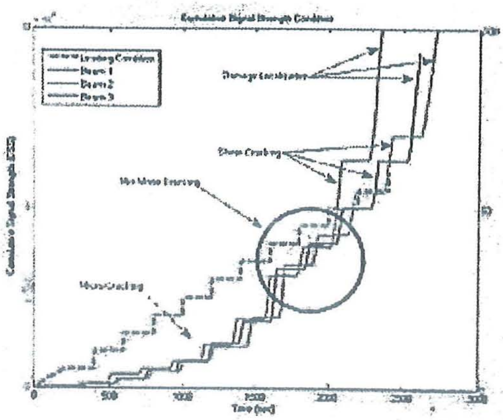

Figure 5 Relationship between CSS and loading condition

A. Result Analysis

The graph in Fig. 5 presented the relationship between loading conditions on the left side vertical axis and cumulative signal strength (CSS) on the right side vertical axis for three beam specimens. The stages of loading analysis were divided according to the observation during the testing and based on the former research work by [18]. Generally, the increment of load phase is related to the development of crack. It was found that the maximum loads for all specimens are between of 65 KN and 70 KN. Each step of loading conditions represented the mechanical behavior of the reinforced concrete beam. Then, it was proved by analyzing the AE signal strength data as presented in Fig 5. The CSS value for all beams reached to the maximum in the 11th load phase.

During testing, it was possible to observe visually the crack initiation and growth after each of the loading phase. In the phase 1 to phase 2, the initiation of micro-cracking had been occurred where gradually growth to tensile and mix-mode stage cracking. According to [13], three stages of cracks generally developed under test load; namely initiation phase, the active phase and inactive phase. In crack initiation phase, micro cracks were developed and formed in the interfacial transition zones. The AE events were produced by small energy contents and medium amplitudes. Then, the subsequent loading phase expresses the dramatically increase of the crack growth when the load reached about 60 % of ultimate load capacity and normally shear cracking are appeared in this stage. It is also classified as the active phase of cracking. The damage localization was occurred right after shear cracking process and considered as inactive phase, where a significance increase in AE hit and energy rates is always

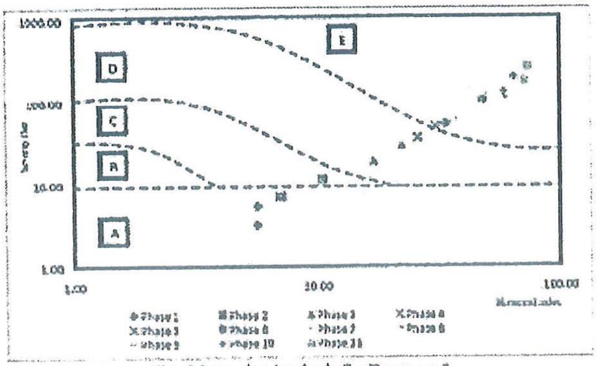

Fig. 6 Intensity Analysis for Beam no 1

formed during shear crack. This trend is clearly reflected in the intensity analysis chart as well.

B. Intensity Analysis

During the stepwise loading of reinforced concrete beam, AE signal could be due to different source, such as cracks opening and propagation or friction of existing crack surface which could occur during opening or closure existing cracks [17]. Due to that matter, the damages of the structure are accumulating related to a modification of AE pattern. That modification could be manifested by the global health indexes, which were proposed previously in Equation 1 and 2[16-17].

Fig. 6 – 8 shows the intensity analysis chart at channel 2 for 3 specimens of beams. These selected channels are according to the high attenuation in AE signal and the charts are plotted based on the maximum value of HI and Sr.

Basically, the charts are divided into intensity zones that identify the structure performance and the significance of a given sequence of AE signal data as presented in Table 1[14]. Due to the signal strength analysis, it was carried out based on the number of load phases. The total number maximums of load phases represented in this investigation are eleven phase as presented in Fig. 6 - 8. It is also found that the charts plotted for all beams specimens were represented almost similar to the trend of phase distribution in the zones. The IA was divided into five zones (Zones A, B, C, D and E) to classify the damage level of the beams.

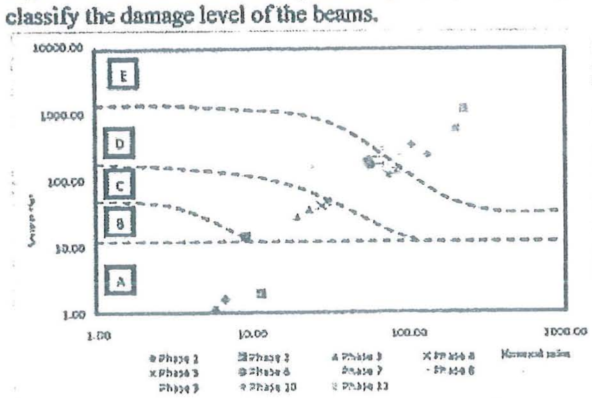

Fig. 7 Intensity Analysis Beam no 2

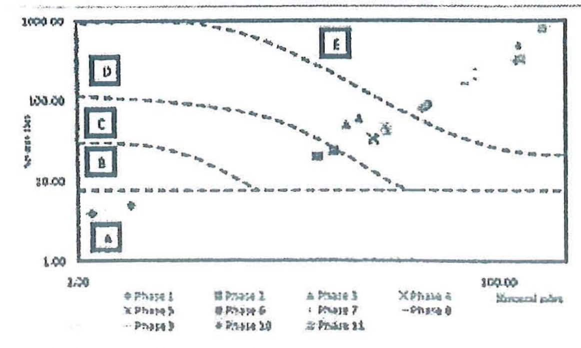

Fig. 8 Intensity Analysis for Beam no 3

One of the first observations in these entire charts from Fig 6 - 8, mostly the load Phase 1 is indicated a low severity values (zone A) where as, there are no insignificant acoustic emission in this phase. However, most of the load Phase 2 was laid on zone C and not in Zone B. This happened according to the stages of the loading process and also the initial defects started to occur in this load phase. Comparing to the next load phase up to the failure stage, the values were indicated gradually increase up to zone E, where as this zone intensity are the major defects and requires the follow up inspection.

This theoretical calculation was pointing that the beam should begin to show hairline cracks at the tensile portion of the beams at about 12% of the ultimate load. In addition, about 50% to 70% of ultimate load the intensity values appear to imply the flexural and shear cracks as presented in figure 5. Throughout this time, the intensity values indicated that sufficient warning to estimate the severity of damage in the beams. Once the loads increase to this limit, it definitely indicates a serious damage to the beams and requires immediate remedial measure to be taken for preventing the failures of the specimens.

All the Zones as shown in the figure 6 - 8 are proposed based on the brief observation above and it is also related to the AE signal strength data. This chart is valid for evaluating the reinforced concrete beams of the same dimension and subjected to the similar load condition. However, the results can be summarized that, intensity analysis is one of the effective methods in evaluating the damage level mechanism for *concrete structure.

VI. Conclusion

Based on the analysis of AE signal strength presented in this paper, the following conclusion can be drawn:

The integrity of the concretes structures members can be sufficiently quantified by using the intensity analysis. Besides that, this method shows the great potential in becoming an effective tool for evaluations and continuous monitoring for all fields of concretes structures.

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