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**GOVERNMENT OF INDIA**
**MINISTRY OF RAILWAYS**

# GUIDELINES ON USE OF ACOUSTIC EMISSION TECHNIQUE (AET) ON RAILWAY BRIDGES

## BS- 104

**SEPTEMBER - 2009**

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**B&S DIRECTORATE**

**RESEARCH DESIGNS AND STANDARDS ORGANISATION**
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# GUIDELINES ON USE OF ACOUSTIC EMISSION TECHNIQUE (AET) ON RAILWAY BRIDGES

## 1.0 GENERAL:

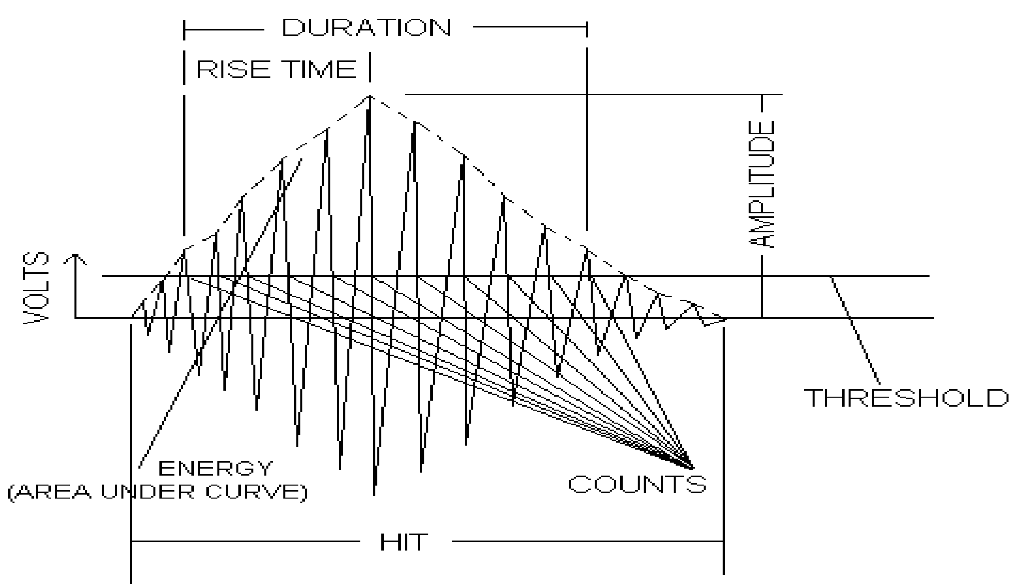
RDSO had earlier issued guidelines on use of acoustic emission technique on Railway Bridges and published as Report No. BS 51 in Dec, 2002. Further, a pilot project on acoustic emission testing of Railway bridges has been completed by N. Railway from M/s TISEC, Canada. Under this pilot project, two bridges were tested for acoustic emission by the system developed by M/s TISEC. RDSO has also carried out acoustic emission testing of bridges on Indian Railways and have also published reports.

Railway Board vide letter No.2003/CE-I/BR-III/2(Pt.) dt.6.2.2007 has constituted a committee to critically examine and analyzing the details and outcome of pilot project and provisions in International codes and Manuals on this subject and come out with the "Guidelines for Acoustic Emission testing of Railway bridges". The members of the committee are as below:

1. EDBS, RDSO, Director/B&S(SB-II)-Alternate, Convenor
2. CBE/Northern Railway, New Delhi
3. CBE/Western Railway, Mumbai

Accordingly this revised guidelines on use of acoustic emission testing (AET) on Indian Railway bridges is being issued.

## 2.0 GLOSSARY OF COMMONLY USED AE TERMS:




i) **Acoustic Emission (AE):** Elastic wave generated by the rapid release of energy from sources within a material.

ii) **Wave form:** It is a pattern of oscillating motion which sustains itself without change in form as it travels through the material. The pattern of motion travels at a very specific speed that depends on material properties and geometry.

iii) **Source**: The physical origin of one or more AE events.

iv) **Zone**: The area surrounding a sensor from which AE can be detected.

v) **Burst Emission**: A qualitative description of the discrete signal related to an individual emission.

vi) **Continuous Emission:** A qualitative description of the sustained signal level produced by rapidly occurring acoustic emission events.

vii) **Threshold:** It is the level of amplitude set before starting the AE monitoring for removing unwanted data.

viii) **Amplitude:** It is the highest peak voltage attained by an AE waveform. The amplitudes of acoustic emissions are customarily expressed on a decibel (dB) (logarithmic) scale.

ix) **Counts:** These are the threshold-crossing pulses. Counts depend on the magnitude of the source event, but they also depend strongly on the acoustic properties of the material.

x) **Energy:** is the measured area under the rectified signal envelope. ENERGY is preferred over counts because it is sensitive to amplitude as well as duration and it is less dependent on threshold setting and operating frequency.

xi) **Duration:** is the elapsed time from the first threshold peak to the last threshold peak. It is measured in microseconds.

xii) **Rise Time:** is the time from the first threshold to the signal peak.

xiii) **Hit:** is any signal that exceeds the threshold and causes the system channel to accumulate the data.

xiv) **Event:** is a local material change giving rise to acoustic emission.

xv) **Channel:** is a single AE sensor and the related equipment components for the transmitting, conditioning, detecting and measuring the signals that come from it.

xvi) **Frequency:** for an oscillating signal or process, the number of cycles occurs in unit time.

xvii) **Intensity:** is a measure of the size of emission signals detected, such as the average amplitude, average AE energy or average counts.

xviii) **Parametric Inputs**: Environmental variables (e.g. load, strains pressure, temperature) that are measured and stored along with the AE data.

xix) **Sensor:** a device containing a transuding element that turns AE wave motion into an electrical voltage.

xx) **Attenuation:** loss of amplitude with distance as the wave travels through the test structure.

xxi) **dBae(**A) :unit of measurement for AE signal amplitude.

A is defined by

A (dBae) = 20 log $V_p$

Where $V_p$ is the peak signal voltage in micro volts referred to the preamplifier input.

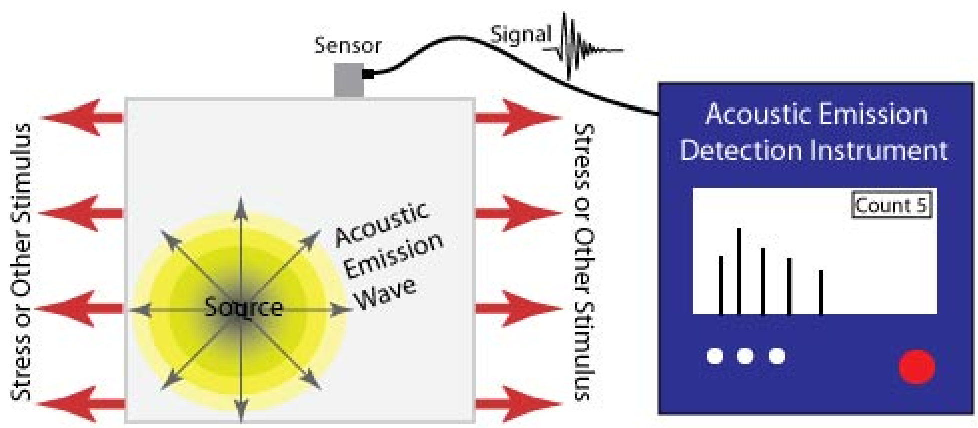
xxii) Stimulus : change in pressure, load, or temperature

xiv) Frequency filature: The frequency filter is used to eliminate unwanted frequency ranges (noise sources) and matches the measurement chain to the requirements of the application.

## 3.0 INTRODUCTION OF AE TECHNIQUE:

## 3.1 ACOUSTIC EMISSION (AE):

It refers to the generation of transient elastic waves produced by a sudden redistribution of stress in a material. When a structure is subjected to an external stimulus (change in pressure, load, or temperature), localized sources trigger the release of energy, in the form of stress waves, which propagate to the surface and are recorded by sensors. With the right equipment and setup, motions on the order of picometers ($10^{-12}$ m) can be identified. Sources of AE vary from natural events like earthquakes and rockbursts to the initiation and growth of cracks, slip and dislocation movements, melting, twinning, and phase transformations in metals.




Material emit at places were the local stress is high enough to cause fresh, permanent deformation. Often this happens at stress concentrations, places where the stress is raised by local geometry, stress concentrations exist at weld details, changes in section and structural discontinuities in general they also exist around cracks and flaws. The stress concentrations at weld details are the reason why fatigue cracks initiate at these locations.

When a material deforms and emits, the deformation tends to relieved the high local stresses. Often the load is thrown onto some other part of the structure. This has a stabilizing effect. If the structure is unloaded and then reloaded to the same level, other region that deformed the first time will tend to be stable the second time. Thus, the emission sources will tend not to re-emit the second time round, unless the load exceeds the previous.

The AE behavior of materials is time-dependent. It takes time for a material to come into equilibrium with an imposed load. The technical term for a material's response to applied load ( stress ) is " strain". Strain is a measure of the change in shape that occurs when the material is loaded. The strain has an electric, reversible component and also ( if the load is high enough ) a plastic, permanent components.

The elastic component of the strain occurs immediately the load is applied. This is a redistribution of the force field inside the material such that all the forces are balanced. This redistribution takes place at the speed of sound.

The plastic component of the strain often takes longer. Some of the deformation is immediate but some of it is delayed. There is a hint of silly putty in the behavior of every material. Given enough time, plastic creep and stretch and wooden beams sag. Steel shows only a trace of this kind of behavior, but acoustic emission is a very sensitive indicator and will often reveal time-dependent behavior that would otherwise go unnoticed. This is illustrated in figure1 ,which shows the characteristic behavior pattern of a newly fabricated component. In this figure, load and AE are both plotted against time. The load is raised and held, then raised and held again. AE is generated during both load rises. During the first load hold, there is no emission. But during the second load hold the stress is higher.

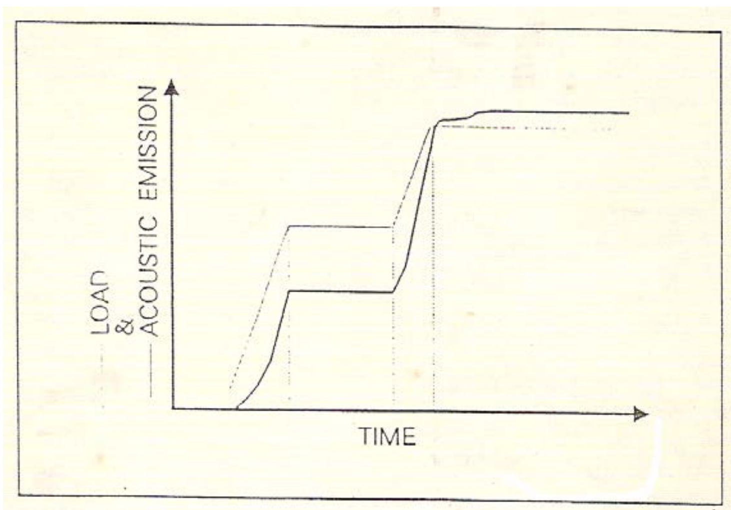



Fig. 1 Emission continuing during load hold indicates instability.

The emission continues for some time into the second hold period, then eventually the component stabilizes.

Emission that consumes during load holds is likely to indicate structurally significant defects. Many test procedures place particular emphasis on emission during load holds. Emission that occurs during rising load on previously unloaded structures is less easy to interpret: it may come from defects, but good material will also emit during rising load the first time is loaded. The interpretation of emission during load hold is more clear-cut.

Another characteristic of structurally significant defects is that they tend to emit on a second loading. If a second loading is carefully monitored, one often sees a little emission before the previous maximum load: not nearly as much as the first time, but not zero either. This emission can be an important indicator of structural instability.

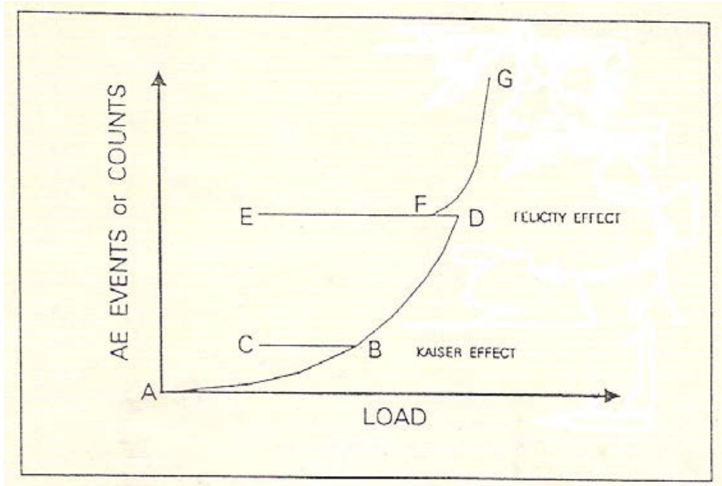



Fig. 2   Emission repeating loading.

This is illustrated in fig. 2 . Here emission is plotted directly against load.  In this scenario the load is raised, lowered, raised again to  a higher level, lowered and finally raised to a higher level still.  Emission  is generated during the fist load raise (AB) , but as the load lowered (BC) and raised

again ( CB) there is no more emission, until the previous load maximum is exceeded. Emission continues as the load is raised further ( BD), and stops as the load is lowered for the second time (DE),.  On raising the load for the last time, a different emission pattern is observed:  the emission starts up before the previous maximum load is attained ( F).  Emission continues as the load is increased (FG).

The  behavior observed at point B ( no emission until previous maximum load is exceeded) is known as Kaiser Effect.  The behavior observed at point F ( Emission at a load below the previous maximum ) is know as the Felicity effect.  Insignificant flaws tend to show the Kaiser Effect while structurally significant flaws tend to show the Felicity Effect.

For AE monitoring the highway bridges, the main interest is structural fatigue.  The emission behavior of growing fatigue cracks has been extensively studied ( Ref.2). Classic laboratory data is shown in fig. 3 .  This diagram shows both the crack length, and the accumulated total of the emission detected.  The emission began with crack initiation, and then tracked rather closely with the growth of the crack, increasing rapidly as the crack propagated faster and faster towards failure.

This experiment was carried out with cyclic loading using a fixed load amplitude.  It was found that the primary emission from active crack growth occurred only at  the peak load levels.  In fact, fig. 3 shows only the emission that occurred at the peak load levels, secondary emission and noise that occurred at lower load levels  were gated out.  At first when the crack was still small, not every cycle produced emission.  But later as the crack approached the critical length for unstable propagation, every cycle produced emission. This fits well with the behavior of statically loaded specimens discussed above, that insignificant flaws tend to show the Kaiser Effect while structurally significant flaws tend to show the Felicity Effect.

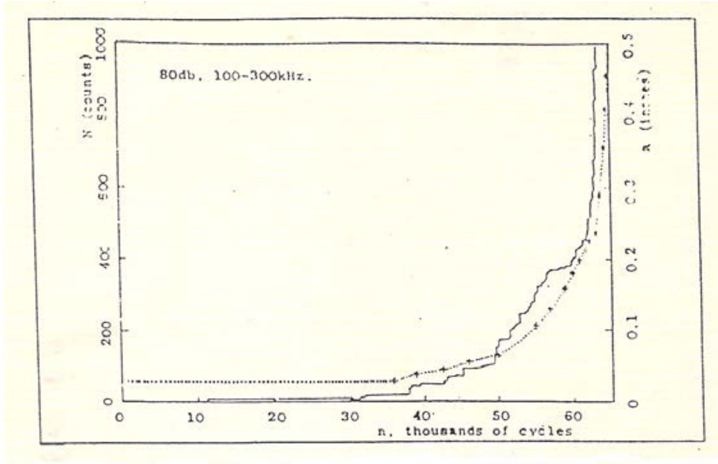



Fig. 3 AE from Growing Fatigue Crack

The primary emission from growing fatigue cracks can come from two sources . First, there may be emissive particles, typically on-metallic inclusions, in the stress-concentrated region near the crack tip. As the crack advances towards these particles the local stress on them rises, and their breaking will produce primary emission. The other source is the movement of the crack tip itself. Crack tip movement is typically taking place in a mixed mode: some of new surface is created by dislocation activity and some of it is created by small scale cleavage, a sudden separation of the material in a region of local weakness and / or exceptionally, high stress. Crack tip movement by dislocation activity is typically not detectable, but cleavage is an abrupt and relatively gross mechanism that produces plenty of AE energy in the normally detectable range.

Secondary activity from crack face friction is also often observed in AE monitoring fatigue cracks. In constant-cycle fatigue this activity often produces jut the same signal cycle after cycle, at intermediate load levels. This secondary emission may continue for hundreds or thousands of cycles then die out only to start again later in the test. The best explanation is that it is produced by rubbing at rough spots or "asperities" on the cracks surface, as show in fig. 4. It has also been suggested that the freshly created surfaces at the crack tip may stick together then break apart again as the crack tip opens and closes.

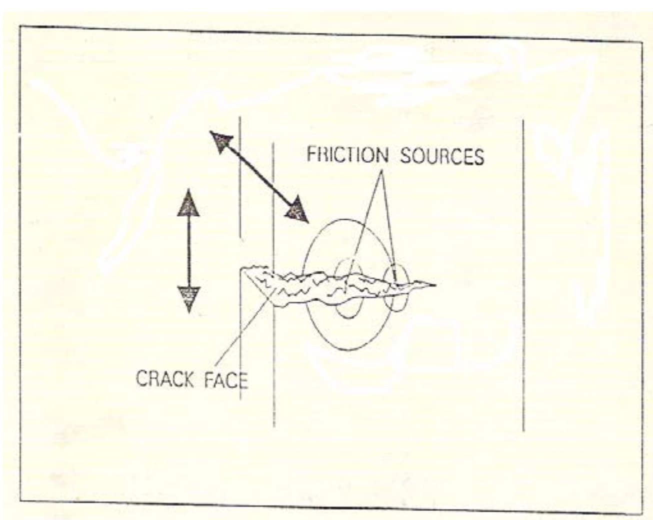



Fig. 4 Crack Face Rubbing can Produce Secondary Emission.

Theoretical relationships between AE and crack propagation rates have been developed Extensive research work has been done on AE from constant-cycle fatigue, less work has been done on the random – cycle fatigue that is more important for highway bridges monitoring.

Distinguishing between primary and secondary emission is easy in the case of constant-cycle fatigue. In the case of random cycle fatigue on bridge it is not so easy, and may be not so necessary either, crack face movement, either friction or fresh growth, is an undesirable and probably deteriorating condition that should be corrected.

**3.2** AET is among one of the latest NDT methods which can be used for the condition assessment of bridges and can be useful in setting priority for replacement /repair of affected bridge members. This technique has also been used for monitoring cracks in bridges by some of the advanced countries.

**3.2** AE technique has become more popular in the recent years as a service inspection tool and is being used widely for evaluation of a variety of material and engineering structures. This technique is already in use in oil industry for monitoring corrosion and leak detection, in air craft industry by National Aeronautical Laboratory, Bangalore, in Nuclear reactors by Indira Gandhi Centre for Atomic Research and Bhabha Atomic Research Center and in Rocket Industry by ISRO, SHAR center & Vikram Sarabhai Space Centre.

**3.3** Damage assessment has been feasible because AE activities are function of parameters such as stress level in the crack Zone. AE activity can be directly related to fracture mechanics parameters which can be further related to crack growth rate and fatigue failure.

**3.4** In case of railway bridges, testing is carried out in situation where background noise is usually high. It is essential to understand the noise sources and elimination of their influence on the AE testing and analysis. A pre test noise survey helps in identifying desirable noise sources, their frequency /magnitude, ways to eliminate or reduce them, selection of sensors, instrument system and test procedure. It will also help in knowing whether the AE signals can be detected avoiding noise.

**3.5** The basic theory of Acoustic Emission along with list of RDSO Reports on the Acoustic Emission testing of Bridges is given in the Annexure-1.

## 4.0 METHODOLOGY OF TESTING:

### 4.1 AE Source Location Techniques:

**Multi-Channel Source Location Techniques:**

Locating the source of significant acoustic emissions is often the main goal of an inspection. Although the magnitude of the damage may be unknown after AE analysis, follow up testing at source locations can provide these answers. As previously mentioned, many AE systems are capable of using multiple sensors/channels during testing, allowing them to record a hit from a single AE event. These AE systems can be used to determine the location of an event source. As hits are recorded by each sensor/channel, the source can be located by knowing the velocity of the wave in the material and the difference in hit arrival times among the sensors, as measured by hardware circuitry or computer software. By properly spacing the sensors in this manner, it is possible to inspect an entire structure with relatively few sensors.

Source location techniques assume that AE waves travel at a constant velocity in a material. However, various effects may alter the expected velocity of the AE waves (e.g. reflections and multiple wave modes) and can affect the accuracy of this technique. Therefore, the geometric effects of the structure being tested and the operating frequency of the AE system must be considered when determining whether a particular source location technique is feasible for a given test structure.

**Linear Location Technique:**

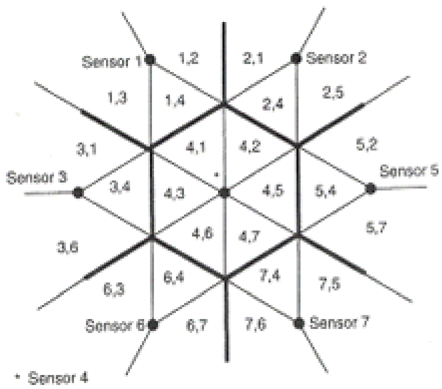
Several source location techniques have been developed based on this method. One of the commonly used computed-source location techniques is the linear location principle shown to the right. Linear location is often used to evaluate struts on truss bridges. When the source is located at the midpoint, the time of arrival difference for the wave at the two sensors is zero. If the source is closer to one of the sensors, a difference in arrival times is measured. To calculate the distance of the source location from the midpoint, the arrival time is multiplied by the wave velocity. Whether the location lies to the right or left of the midpoint is determined by which sensor first records the hit. This is a linear relationship and applies to any event sources between the sensors.

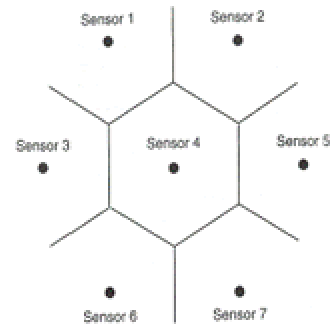
Because the above scenario implicitly assumes that the source is on a line passing through the two sensors, it is only valid for a linear problem. When using AE to identify a source location in a planar material, three or more sensors are used, and the optimal position of the source is between the sensors. Two categories of source location analysis are used for this situation: zonal location and point location.

### Zonal Location Technique

As the name implies, zonal location aims to trace the waves to a specific zone or region around a sensor. This method is used in anisotropic materials or in other structures where sensors are spaced relatively far apart or when high material attenuation affects the quality of signals at multiple sensors. Zones can be lengths, areas or volumes depending on the dimensions of the array. A planar sensor array with detection by one sensor is shown in the upper right figure. The source can be assumed to be within the region and less than halfway between sensors.

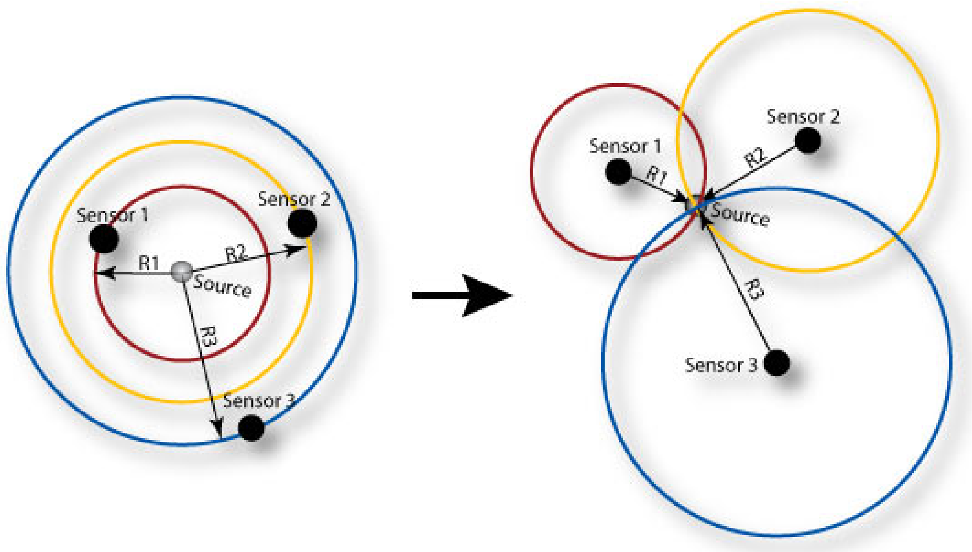
When additional sensors are applied, arrival times and amplitudes help pinpoint the source zone. The ordered pair in lower right figure represents the two sensors detecting the signal in the zone and the order of signal arrival at each sensor. When relating signal strength to peak amplitude, the largest peak amplitude is assumed to come from the nearest sensor, second largest from the next closest sensor and so forth.




### Point Location

In order for point location to be justified, signals must be detected in a minimum number of sensors: two for linear, three for planar, four for volumetric. Accurate arrival times must also be available. Arrival times are often found by using peak amplitude or the first threshold crossing. The velocity of wave propagation and exact position of the sensors are necessary criteria as well. Equations can then be derived using sensor array geometry or more complex algebra to locate more specific points of interest.




## 4.2 Selection and Mounting of Sensor:

After selecting proper sensors i.e. R 3I or R 6I for concrete surfaces and R 15I or R 30I for steel surfaces, careful examination of part of structure to be monitored is carried out and suitable location technique i.e. linear/ planer location etc. is decided, accordingly location for mounting sensor is decided.

For sensor mounting, the surface is prepared after removing any dirt or paint in case, paint layer is too thick, it is not necessary to remove the paint. The plane surface should be clean and rubbed with sand paper for smoothness. The sensor is mounted after placing suitable couplant and using magnetic hold-downs. On concrete surface, MS sheet of size 50 x 50 mm are fixed using suitable adhesive on the surface for placing magnetic hold-downs to keep sensors in position.

### 4.3 System Set Up and Operating Procedure:

For getting an idea of the presence of cracks only critical locations should be analysed ( members which are having higher stresses are critical).

After placing equipments in instrumentation hut and mounting of sensors at respective position, they are connected to data acquisition system through coaxial cables. Following connection is performed:-

a) Connect the UPS to main power supply with proper earthing.

b) Connect the output to UPS to AE system.

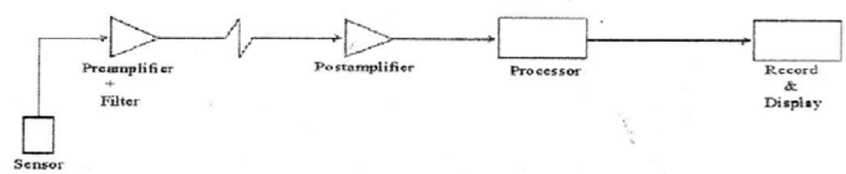
c) Ensure UPS is connected with single phase 230 V, AC supply.

d) Connect key board, mouse & monitor to the main supply

e) Turn on the main supply, UPS and the AE equipment subsequently.

f) Brief Operational Procedure for making system ready for data acquisition is given in Annexure – 2.

The AE instrumentation setup is shown as below :-




AE instrumentation setup

### 4.4 System Performance Check:

For reliable AE data it is essential that the channel sensitivity be well matched and consistent. This is achieved by system performance check. It ensures a check of the effectiveness of sensor mounting and coupling It reveals any week channel that needs correction before actual data acquisition. After the sensors have been mounted, the cables from sensors are connected to the system. The system performance check is carried out by using pencil lead break technique. A repeatable acoustic wave is generated by carefully breaking a pencil lead between the sensors on the test specimen. The pencil is kept at $45^0$ with the surface. When the lead breaks, there is a sudden release of the stress on the surface of specimen of amplitude 85 to 95 dB .Other details of the pencil lead is given below:

| | | |
|---|---|---|
| Length of the tip of the pencil | = | 2 to 3 mm |
| Dia of pencil lead | = | 0.5 mm (these dia and hardness is specified because it is more readily available and gives larger signal) |

Hardness = 2H

The detection of active flaw location using Lead Brake Technique is given in Annexure-3.

**4.5 Test Duration:**

In defining the aims and objectives of the test the practitioner must also define whether the test is long or short term i.e. is the investigation a temporary study or fact finding mission, or is the test a prolonged or permanent monitoring project which aims to detect or predict the presence of damage mechanisms at an early stage. Both global and local monitoring can be long-or short-term undertakings.

**4.6 Stimulus or Loading:**

Normal sectional trains can provide stimulus or loading of the bridge for acoustic emissions. If the frequency of normal sectional trains is less, runs of special trains can be used for the loading.

**4.7 General Noise Elimination Methods:**

Noise is eliminated in following ways:

- By selecting an appropriate test strategy and instrumentation setup.
- By taking practical precautions at site to eliminate noise source as far as possible.
- By recognizing & removing noise indications form the recorded data.

It is possible to reduce / eliminate noise signals from other AE signals using filters, reducing the gain and adjusting threshold. However, the disadvantage is that it would also affect the AE data. It is also possible that some of the AE signals with frequency components in the range same as noise may get filtered out. There are various methods of eliminating the noise from processing by an appropriate test strategy and instrumentation setup. These are:-

- Spatial filtering
- Parametric filtering
- Signal filtering

i) **Spatial Filtering: -** AE techniques can locate emission sources which are calculated from the time difference in the arrival of emissions event signals at two or more positioned sensors in linear, triangular or rectangular placement. The source must be located within the area or line bounded by locating sensor array to effectively filter out and noise sources outside the crack monitoring array. Multiple wave paths as the monitored part can cause erroneous source location results, which can be corrected by using guard sensors for zone isolation. These sensors are positioned so that any emission even originating outside the area of interest would arrive at these sensors first. Knowing the location of possible noise source would greatly enhance the effectiveness of guard sensors.

ii) **Parametric Filtering:** - It is usually done with a strain measuring device beyond a certain level. AE detected at levels below this can be filtered out as noise. This method is particularly effective in distinguishing between AE from actual flaw growth and AE produced by interaction of crack faces during compression including possible AE produced by crushing of corrosion products between crack faces in environmentally exposed defects.

iii) **Signal Filtering:** - In this filtering, peculiarities in the features of AE signals from different sources are used. These features are a function of several variables including nature (or rate of energy release) of AE source, material and geometry of the structure through which the AE waves propagate, sensor's resonant properties and the distance from noise source to sensor.

If the range of a time domain parameter of AE from crack growth, such as amplitude, can be established, filters can be adjusted to exclude all detected signals that do not fall within this range. More effective filtering is achieved as more parameters are included. Some AE data acquisition systems have such methods of filtering as standard features. For example, AE from cracks are known to have short rise times as compared to the signal duration. It would thus be a simple step to eliminate noises that have long rise times.

Features from the frequency domain can be used to distinguish noise. Most of the mechanical noises, like those generated by machinery, have frequencies less than 50 KHz. A sensor whose resonant frequency is higher than that of noise will not receive such noise signals. Full frequency analysis can be used to eliminate further noise such as fretting, with frequency domain properties less evidently different from crack emissions.

### 4.8 Precautions at Test Site:

By taking particular precautions at the test site, the noise can be eliminated as follows:

| | | |
|---|---|---|
| 1. | Noise caused by people | Perform test when they are not around or inform that work is going on and the need to be quite |
| 2. | Frictional Noise | Tighten fasteners to eliminate rubbing |
| 3. | Mechanical Noise due to loose fitting parts | Tighten fasteners |
| 4. | Rain | Postpone test |
| 5. | Electrical Noise | Proper shielding and grounding |

## 5.0 ANALYSIS OF AE SIGNALS:

**5.1** The heart of any AE system is its data analysis capability. The basic objective of data analysis is to identify signals of interest while rejecting non-interesting signals (noise). Another objective is to be able to perform the data analysis in real time while the test is being conducted. A compromise must always be made between too little data analysis and too much, especially when real time analysis is being done. If there is too little data for analysis, then a lot of uninteresting "noises" will contaminate the test results, possibly confusing the operator about the integrity of the structure. If there is too much data for analysis, then there are many periods when the system is "dead" and not able to acquire any more data, be it interesting signals or uninteresting "noise".

**5.2** There are multiple levels of signals processing which can be applied to AE signals. The simplest of these is frequency filtering, which consists of passing only those signals falling within a selected band width. This concept is identical to the manner in which a specific radio station is selected from among the many in the RF spectrum. The next level of signal processing consists of special filtration, which consists of passing only those signals originating within a selected area on the structure. This concept is identical to the manner in which an underground nuclear test in a certain location can be differentiated from earth quakes in other locations. Special filtration can be made more complete using “guard” sensors. In this scheme the sensors closer to the region of interest are called data sensor, the “guard” sensors are placed outside of the both the data sensors and the region of interest. Acceptance of an AE signals will occur if and only if the data sensors receive the signal before the guard sensor. If the signal is received by the guard sensor first, it is classified as noise and rejected. Special filtration technique is applied when the AE signals are in an analog form, thus they are inherently fast.

**5.3** Co-relation analysis forms another level of AE signal processing. In this procedure AE parameters like counts, energy, amplitude, rise-time, duration and parametric are plotted against each other in real time. A simple example of the situation when AE duration is plotted vertically against AE amplitude horizontally for the same event. If a signals caused by electromagnetic interference is plotted on this graph, it will appear in the lower right corner since EMI typically has high amplitude but shorter duration. A signal of mechanical origin would trend to plot in the upper left corner of the graph, since mechanical vibration has long duration but low amplitude. AE signals caused by crack extension will trend to plot in a band going from the lower left corner to the upper right corner of the graph, since low amplitude crack signals typically have short duration while high amplitude crack signals typically long duration. Since co-relation analysis is graphical, it does its signal analysis job very quickly and is easily change to accommodate different noises.

**5.4** AT Post Analysis - Noise indications from the recorded data can be removed by post filtering analysis through AT POST SOFTWARE. The purpose of AT post is to filter out unwanted AE data from an AE data file. The program scans through the original data file (the “input file”) and writes in a filtered data file (The “out put file”). The filtered file has structure like the original, with the exception of a filter message which contains information about the parent file and filters used to produce the filtered data files. The filtered file can then be passed through the data acquisition program in replay mode, to provide the final data analysis.

# 6.0 ADVANTAGES AND LIMITATIONS OF ACOUSTIC EMISSION TECHNIQUE

## 6.1 AE in Comparison to the other NDT’s:

Acoustic Emission is unlike most other nondestructive testing (NDT) techniques in two regards. The first difference pertains to the origin of the signal. Instead of supplying energy to the object under examination, AET simply listens for the energy released by the object. AE tests are often performed on structures while in operation, as this provides adequate loading for propagating defects and triggering acoustic emissions.

The second difference is that AET deals with dynamic processes, or changes, in a material. This is particularly meaningful because only active features (e.g. crack growth) are highlighted. The ability to discern between developing and stagnant defects is significant. However, it is possible for flaws to go undetected altogether if the loading is not high enough to cause an acoustic event. Furthermore, AE testing usually provides an immediate indication relating to the strength or risk of failure of a component. Other advantages of AET include fast and complete volumetric inspection using multiple sensors, permanent sensor mounting for process control, and no need to disassemble and clean a specimen.

Unfortunately, AE systems can only qualitatively gauge how much damage is contained in a structure. In order to obtain quantitative results about size, depth, and overall acceptability of a part, other NDT methods (often ultrasonic testing) are necessary. Another drawback of AE stems from loud service environments which contribute extraneous noise to the signals. For successful applications, signal discrimination and noise reduction are crucial.

The consequences of these fundamental differences are summarized in table given below.

| **Acoustic Emission** | **Other NDT Methods** |
|---|---|
| i) Detects movement of defects | Detects geometric forms of defects |
| ii) Requires stress | Do not requires stress |
| iii) More material sensitive | Less material sensitive |
| iv) Less geometric sensitive | More geometric sensitive |
| v) Less intrusive on Plant/ process | More intrusive on plant/process |
| vi) Requires access only at sensors | Requires access to whole area of inspection |
| vii) Tests whole structure at once | Scan local regions in sequence |
| viii) Main problem: noise related | Main problem: geometry related |

## 6.2 Advantages:

A major benefit of AE inspection is that it allows the whole volume of the structure to be inspected non intrusively in single loading operation. It is not necessary to scan the structure looking for local defects; it is only necessary to connect a suitable number of fixed sensors, which are typically placed 1m to 6m apart. This leads to major savings in testing large structures, for which other methods requires removal of insulation, decontamination for entry to vessel interiors , or scanning of very large areas

More advantages compared to other NDT methods arise from the basic principles of AE testing:

- It monitors the dynamic reaction of the test object upon the applied load passively and without intervention.
- It often allows detecting sources over a distance of several meters to the sensor.
- It allows real-time monitoring of the growth of known and unknown defects at a given load, even remotely by data transmission e.g. by using a modem/internet.
- It can monitor a structure under operating conditions.

### 6.3 Limitations:

Despite all the advantages of AE testing, we have to clearly point out, that it cannot be applied always and everywhere.

- Defects, which are neither growing nor moving do not produce AE and, thus, cannot be detected.
- According to the Kaiser-Effect, only those defects are detected without exceeding the highest preceding load, which are already active at the actual load level and are endangering the component anyway. Only by increasing the load above the previous maximum load level defects can be found, which do not grow at standard load.
- Evaluation criteria do not exist in form of commonly accessible data, i.e. the rating of AE-results is set firmly to the knowledge and experience of the service provider.
- AE testing is sensitive to process noise exceeding the detection threshold. In case the process noise cannot be stopped, the detection threshold has to be increased, which requires smaller distances between the sensors and, accordingly, more sensors and channels. Above a certain noise level, AE testing is no longer efficient. identifying cracks signal and filtering noise, no d requires experience.
- The equipment is not yet manufactured or produced indigenously and thus needs to be imported.
- The equipment is quite sophisticated and needs careful handling especially during field trials.
- As compared to other NDTs these equipments are bit costlier, bulky and required more understanding and knowledge to handle.
- Presently no work on concrete Bridges using ACCOUSTIC EMISSION Technique has been done.

## 7.0 APPLICATION OF AET FOR RAILWAY BRIDGES:

Growing needs for more reliable and Non-destructive method for bridge Inspection and monitoring besides, present days visual inspection method that currently predominates. It has given rise to the application of the Acoustic Emission to a wide range of field investigations. In many ways AE is well suited to the study of the integrity of such structures since it is capable of continuous in situ monitoring and offer the ability to detect a vide range of damage mechanism in real time. AE offers the potential for the supply for qualitative and quantitative information concerning the condition of a structure via the application of range of methods ranging from simple interference to intelligent signal analysis and classification techniques. AET can be applied on Steel Bridges and Concrete bridges.

a) **Steel Bridge:** The detection of crack in steel bridges and corresponding identification, classification and repair of these cracks plays an important part in the on going maintenance of steel railway bridge by monitoring acoustic emission. It has been possible to identify active cracks, detects new cracks and quantifies the severity of the cracks; provide an assessment of the level of “damage” caused by a crack and assist with the prioritization of repairs.

Maximum stress in old Railway Girder Bridges can be estimated using AE signal with the help of Kaiser Effect. By assessing the structural condition of the bridge at regular interval, time schedule for the maintenance and repair can be drawn. Damage caused by corrosion , fatigue and secondary effects can be accumulated with time and leads to the foundation of fatigue cracks which are difficult to locate during routine visual inspection and may grown undetected until load carrying capacity of the member is severely reduced. Field tests have been conducted on steel girder bridges in order to obtained data on alternation wave propagation and noise. These conform the capability of this method to bridge monitoring. Field trials have indicated that AE can be readily detected over fairly large distance and that testing can occur without the closure of the bridge.

b) **Concrete Bridge**: Practically no work on concrete bridge monitoring has been done at any corner of the globe. Some testing confined to laboratory have been done on RCC beam and rigid frames under static and cyclic loading conditions. Qualitative evaluation and visualization of cracking process in RCC by Movement Tensor Method have also been done.

**On Indian Railways,** this technique can be adopted in the following cases:

i) In steel bridges where crack has been detected in any member by visual inspection or after testing by any NDT or through any NDT techniques. AET can be used to as such location to determine whether the crack is active or dominate.

ii) In the case of old bridges where fatigue life is getting completed, AET can be used at critical location of the member to determine any active hidden flaw.

iii) To test the location of old existing cracks in the bridge member to assess whether it becomes active by permitting higher axle load.

iv) Maximum stress in old Railway Girder Bridges can be estimated using AE signal with the help of Kaiser Effect. By assessing the structural condition of the bridge at regular interval, time schedule for the maintenance and repair can be drawn.

## 8.0 CASE STUDY:

Lab tests were conducted on steel and concrete specimen for study & locations of AE signals. Case studies for some of the laboratory and field tests are placed at Annexure-4.

## 9.0 CONCLUSION:

1. The AE testing detects defects, which are growing under load during the test but does not recognize defects that are not moving.

2. Because of its capability to detect defects right at the moment of their growth, the AE testing method may also be used as a real-time monitoring and warning system to avoid a failure of the structure under test with possibly disastrous consequences. This drastically reduces the costs as well as harmful impacts on structures caused by moving loads on the bridges**.**

3. This technology has potential to check the quality of the welding, state of corrosion etc. but it has to be ascertained after conducting more trials. It is also feasible to check the entire bridge by large number of AE sensors to assess the total condition of bridge. This kind of AE test has been often applied to large sections of pressurised equipments in oil refineries, large storage tanks and other engineering structures.

## 10.0 RECOMMENDATIONS:

If active flaw is detected by AET, further remedial measure can be planned based on criticality of the bridge member.

In case the flaw is assessed as dormant, the test can be repeated depending on criticality of the member and traffic density of the system.

**ANNEXURE-1**

# BASIC THEORY OF ACOUSTIC EMISSION

## 1.0 THEORY OF AE SOURCES:

Acoustic emissions can result from the initiation and growth of cracks, slip and dislocation movements, twinning, or phase transformations in metals. In any case, AE originate with stress. When a stress is exerted on a material, a strain in induced in the material as well. Depending on the magnitude of the stress and the properties of the material, an object may return to its original dimensions or be permanently deformed after the stress is removed. These two conditions are known as elastic and plastic deformation, respectively.

The most detectible acoustic emissions take place when a loaded material undergoes plastic deformation or when a material is loaded at or near its yield stress. On the microscopic level, as plastic deformation occurs, atomic planes slip past each other through the movement of dislocations. These atomic-scale deformations release energy in the form of elastic waves which "can be thought of as naturally generated ultrasound" traveling through the object. When cracks exist in a metal, the stress levels present in front of the crack tip can be several times higher than the surrounding area. Therefore, AE activity will also be observed when the material ahead of the crack tip undergoes plastic deformation (micro-yielding).

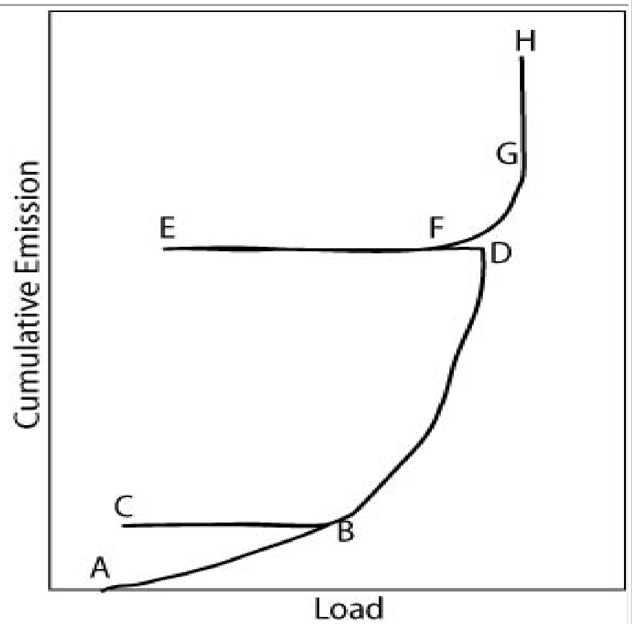
Two sources of fatigue cracks also cause AE. The first source is emissive particles (e.g. nonmetallic inclusions) at the origin of the crack tip. Since these particles are less ductile than the surrounding material, they tend to break more easily when the metal is strained, resulting in an AE signal. The second source is the propagation of the crack tip that occurs through the movement of dislocations and small-scale cleavage produced by triaxial stresses.

The amount of energy released by an acoustic emission and the amplitude of the waveform are related to the magnitude and velocity of the source event. The amplitude of the emission is proportional to the velocity of crack propagation and the amount of surface area created. Large, discrete crack jumps will produce larger AE signals than cracks that propagate slowly over the same distance.

Detection and conversion of these elastic waves to electrical signals is the basis of AE testing. Analysis of these signals yield valuable information regarding the origin and importance of a discontinuity in a material.

### 1.1 Activity of AE Sources in Structural Loading:

AE signals generated under different loading patterns can provide valuable information concerning the structural integrity of a material. Load levels that have been previously exerted on a material do not produce AE activity. In other words, discontinuities created in a material do not expand or move until that former stress is exceeded. **This phenomenon, known as the Kaiser Effec**t, can be seen in the load versus AE plot to the right. As the object is loaded, acoustic emission events accumulate (segment AB). When the load is removed and reapplied (segment CB), AE events do not occur again until the load at point B is exceeded. As the load exerted on the material is increased again (BD), AE are generated and stopped when the load is removed. However, at point F, the applied load is high enough to cause significant emissions even though the previous maximum load (D) was not reached. **This phenomenon is known as the Felicity Effect.** This effect can be quantified using the Felicity Ratio, which is the load where considerable AE resumes, divided by the maximum applied load (F/D).




*Basic AE history plot showing Kaiser effect (BCB), Felicity effect (DEF), and emission during hold (GH) 2*

Knowledge of the Kaiser Effect and Felicity Effect can be used to determine if major structural defects are present. This can be achieved by applying constant loads (relative to the design loads exerted on the material) and "listening" to see if emissions continue to occur while the load is held. As shown in the figure, if AE signals continue to be detected during the holding of these loads (GH), it is likely that substantial structural defects are present. In addition, a material may contain critical defects if an identical load is reapplied and AE signals continue to be detected. Another guideline governing AE's is the Dunegan corollary, which states that if acoustic emissions are observed prior to a previous maximum load, some type of new damage must have occurred.

**1.2** **Noises** : In case of railway bridges, testing is carried out in situation where background noise is usually high. It is essential to understand the noise sources and elimination of their influence on the AE testing and analysis. A pre test noise survey helps in identifying desirable noise sources, their frequency /magnitude, ways to eliminate or reduce them, selection of sensors, instrument system and test procedure. It will also help in knowing whether the AE signals can be detected avoiding noise.

Main sources of noise fall into two main categories, Mechanical and electrical.

- **MECHANICAL NOISE:**

i) Environmental noise in laboratory testing includes normal working and noise of tool and plants.

ii) Environmental noise in field testing includes human or animal activities, flowing water, dirt blown by wind, rain etc near the test site.

iii) All kinds of frictional processes in moving parts, mechanical impact, fretting and cyclic loading can be sources of noise during field testing.

iv) Riveted, pinned or bolted structures are normally noisy due to their loose fitting.

v) Thermal expansion/ contraction in welded structure may give noise from uncleaned surfaces due to cracking of mill scale etc.

− **ELECTRICAL NOISE:**

i) Ground loop noise produced by improper electrical grounding of system and structure.

ii) Electromagnetic interference from power switching circuits, radio stations, electrical storms (lightning) and other such sources of electromagnetic radiation in the neighbourhood of the AE equipment.

iii) Noise generated at the front end of the preamplifier. This is a natural, unavoidable type of noise that sets the ultimate limit to available sensitivity.

## 1.3 Pseudo Sources:

In addition to the AE source mechanisms described above, pseudo source mechanisms produce AE signals that are detected by AE equipment. Examples include liquefaction and solidification, friction in rotating bearings, solid-solid phase transformations, leaks, cavitation, and the realignment or growth of magnetic domains.

## 1.4 Theory - Acoustic Waves:

### 1.4.1 Wave Propagation:

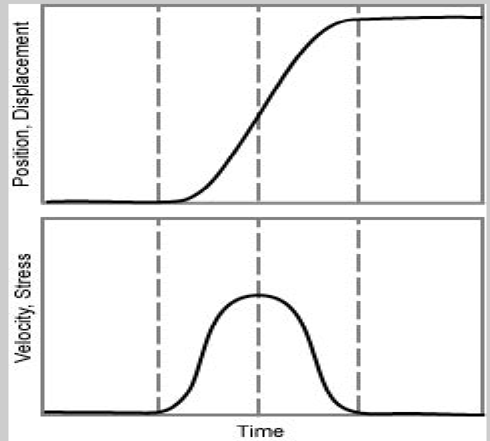
A primitive wave released at the AE source is illustrated in the figure right. The displacement waveform is a step-like function corresponding to the permanent change associated with the source process. The analogous velocity and stress waveforms are essentially pulse-like. The width and height of the primitive pulse depend on the dynamics of the source process. Source processes such as microscopic crack jumps and precipitate fractures are usually completed in a fraction of a microsecond or a few microseconds, which explains why the pulse is short in duration. The amplitude and energy of the primitive pulse vary over an enormous range from submicroscopic dislocation movements to gross crack jumps.

Waves radiates from the source in all directions, often having a strong directionality depending on the nature of the source process, as shown in the second figure. Rapid movement is necessary if a sizeable amount of the elastic energy liberated during deformation is to appear as an acoustic emission.

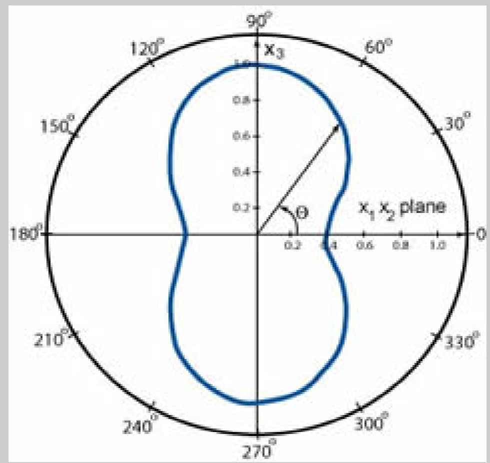
As these primitive waves travel through a material, their form is changed considerably. Elastic wave source and elastic wave motion theories are being investigated to determine the complicated relationship between the AE source pulse and the corresponding movement at the detection site. The ultimate goal of studies of the interaction between elastic waves and material structure is to accurately develop a description of the source event from the output signal of a distant sensor.

However, most materials-oriented researchers and NDT inspectors are not concerned with the intricate knowledge of each source event. Instead, they are primarily interested in the broader, statistical aspects of AE. Because of this, they prefer to use narrow band (resonant) sensors which detect only a small portion of the broadband of frequencies emitted by an AE. These sensors are capable of measuring hundreds of signals each second, in contrast to the more expensive high-fidelity sensors used in source function analysis. The signal that is detected by a sensor is a combination of many parts of the waveform initially emitted. Acoustic emission source motion is completed in a few millionths of a second.

As the AE leaves the source, the waveform travels in a spherically spreading pattern and is reflected off the boundaries of the object. Signals that are in phase with each other as they reach the sensor produce constructive interference which usually results in the highest peak of the waveform being detected. The typical time interval from when an AE wave reflects around the test piece (repeatedly exciting the sensor) until it decays, ranges from the order of 100 microseconds in a highly damped, nonmetallic material to tens of milliseconds in a lightly damped metallic material.



Primitive AE wave released at a source. The primitive wave is essentially a stress pulse corresponding to a permanent displacement of the material. The ordinate quantities refer to a point in the material.



Angular dependence of acoustic emission radiated from a growing microcrack. Most of the energy is directed in the 90 and 270° directions, perpendicular to the crack surfaces.

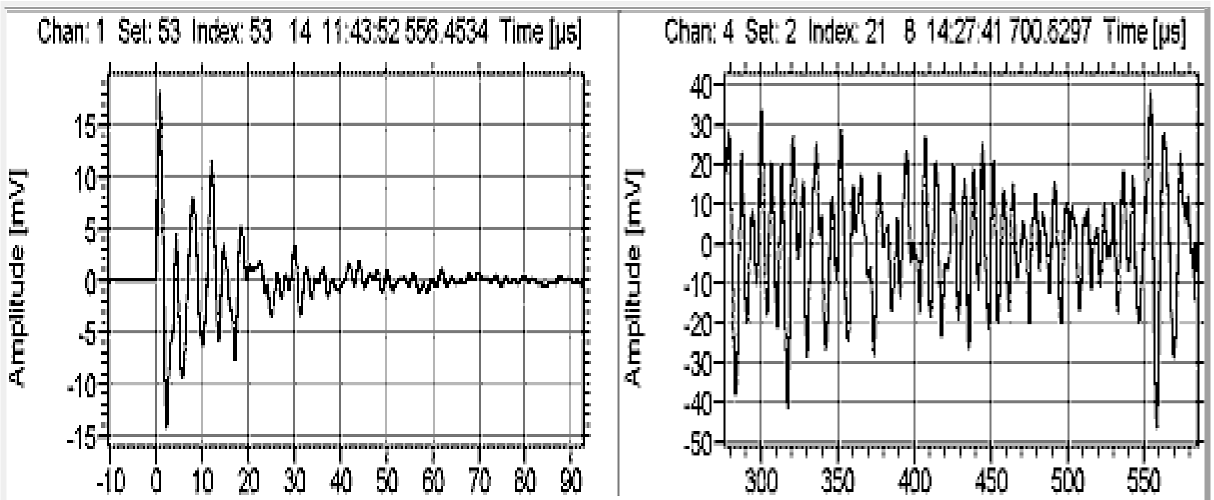
### 1.4.2 Attenuation:

The intensity of an AE signal detected by a sensor is considerably lower than the intensity that would have been observed in the close proximity of the source. This is due to attenuation. There are three main causes of attenuation, beginning with geometric spreading. As an AE spreads from its source in a plate-like material, its amplitude decays by 30% every time it doubles its distance from the source. In three-dimensional structures, the signal decays on the order of 50%. This can be traced back to the simple conservation of energy. Another cause of attenuation is material damping, as alluded to in the previous paragraph. While an AE wave passes through a material, its elastic and kinetic energies are absorbed and converted into heat. The third cause of attenuation is wave scattering. Geometric discontinuities (e.g. twin boundaries, nonmetallic inclusions, or grain boundaries) and structural boundaries both reflect some of the wave energy that was initially transmitted.

Measurements of the effects of attenuation on an AE signal can be performed with a simple apparatus known as a Hsu-Nielson Source. This consists of a mechanical pencil with either 0.3 or 0.5 mm 2H lead in contact with the surface of a material at a 30 degree angle. When the pencil lead is pressed and broken against the material, it creates a small, local deformation that is relieved in the form of a stress wave, similar to the type of AE signal produced by a crack. By using this method, simulated AE sources can be created at various sites on a structure to determine the optimal position for the placement of sensors and to ensure that all areas of interest are within the detection range of the sensor or sensors.

### 1.4.3 Transient and Continuous Signals:

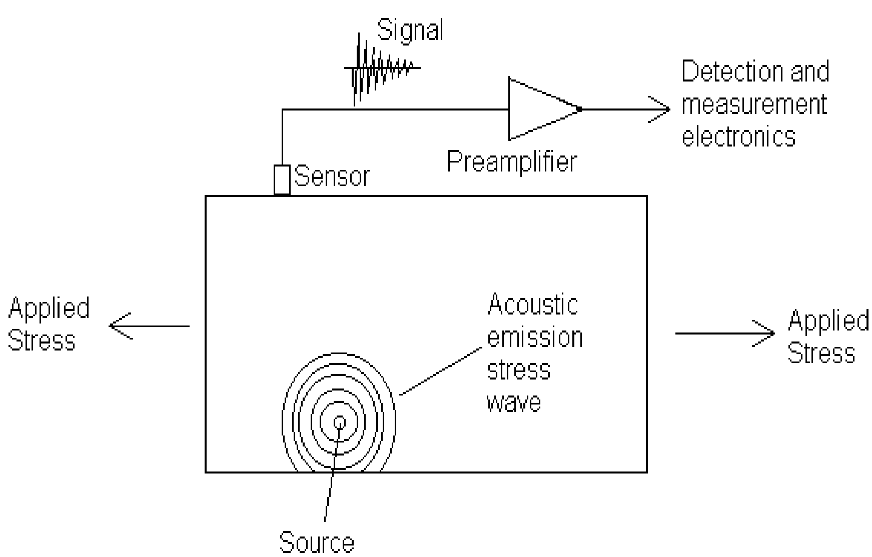
Basically, there are two types of AE signals, transient and continuous signals. With transient AE signals, also called bursts, start and end points deviate clearly from background noise. With continuous AE signals, we can see amplitude and frequency variations but the signal never ends. In figure below, an example of both types of AE signals are shown.




Transient (left) and continuous (right) AE signal.

The useful signals for AE testing at large pressure vessels are burst type signals, e.g. originating from fracture or crack growth. Continuous signals are mostly unwanted (noise) signals such as friction or flow noise. But even burst signals can be interfering signals, e.g. short friction noise or electrical spikes. At the best the background noise is just the electronic noise of the preamplifier or the sensor.

## 1.5 The AE Process Chain:




A process chain always exists at AE testing. The process chain basically consists of the following links:

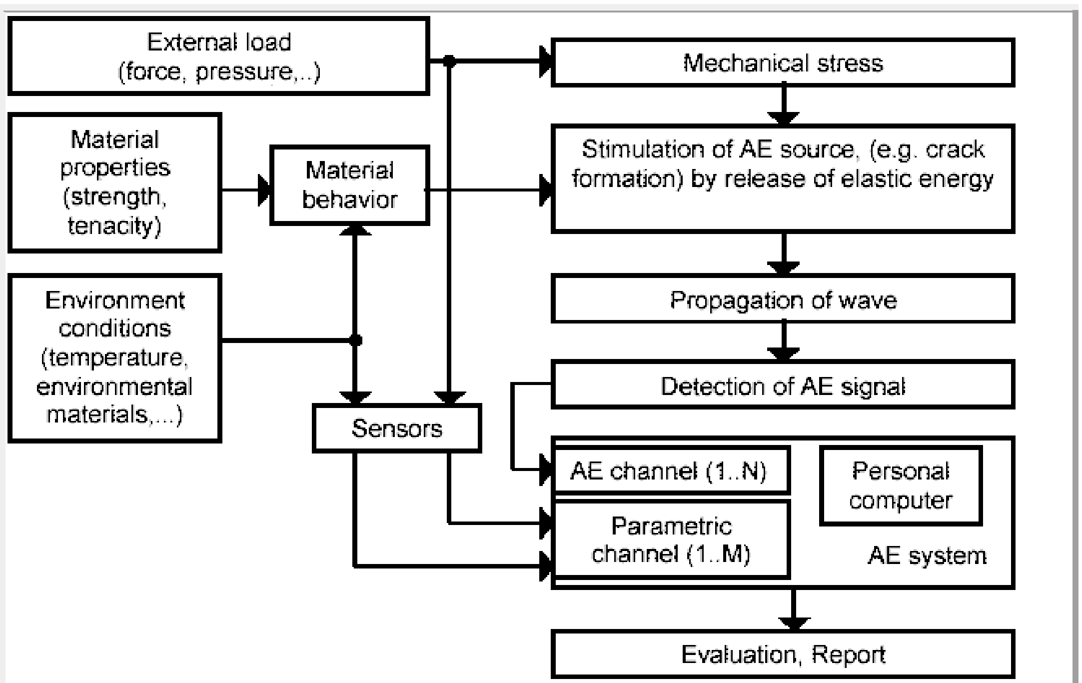
| | | |
|---|---|---|
| 1. | Test object and application of load: | Produce mechanical tensions |
| 2. | Source mechanisms: | Release elastic energy |
| 3. | Wave propagation: | From the source to the sensor |
| 4. | Sensors: | Converting a mechanical wave into an electrical AE signal |
| 5. | Acquisition of measurement data: | Converting the electrical AE signal into an electronic data set |
| 6. | Display of measurement data: | Plotting the recorded data into diagrams |
| 7. | Evaluation of the display: | From diagrams to a safety-relevant interpretation |

As can be seen in figure below, mechanical stress has to be produced within the test object, which is usually done by applying external forces. The behavior of the material and the starting point of the release of elastic energy, e.g. by crack formation, are influenced by the material properties and the environment conditions.

The elastic wave propagating through the material is detected and converted into the electrical AE signal by the AE sensors.

The AE System processes the AE signal, converts the received wave packets into feature data sets, determines the source locations, calculates statistics, and displays them graphically and numerically.

So-called parametric channels measure the environmental conditions as well as the external load as reference parameters for the detected AE.



The AE process chain.

## 1.6 External Parameters:

External parameters, such as pressure or temperature are used as reference for the measured AE data. A parametric channel is a DC signal input, which represents the actual value of an external parameter, such as pressure, temperature, etc.. Figure in the side shows an example for a common display of the total number of events and the pressure vs. time.

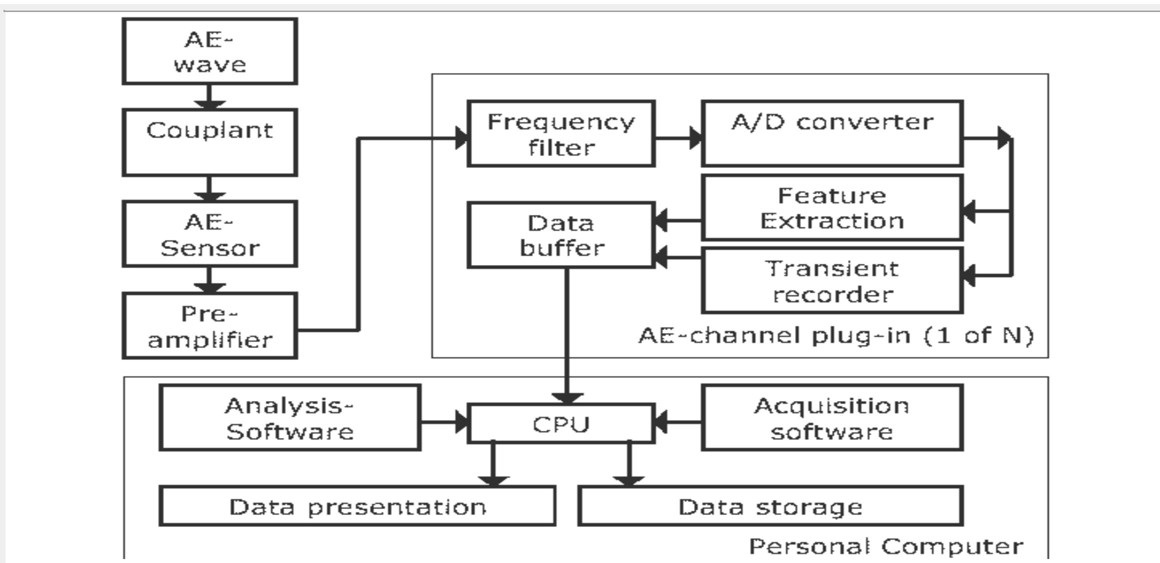
Since the recorded AE activity will be produced mainly by traffic loading and by wind, it is obviously desirable to make a record of these environmental variable along with the AE data. The inspector or engineer interpreting the data can do this job much more confidently if he has information about the cause as well as the effect.

The degree of detail depends on the situation and on the available equipment. As a minimum, the operator must record overall conditions in test log as the monitoring proceeds. Beyond that, it can be useful for the operator to record in the test log some specific traffic or weather incidents heavy truck passing, strong gust of wing) that were seen to produce emission; these incidents can be keyed to the time of test, so that the corresponding data can be received in detail during post test analysis.

Many AE instruments can receive inputs from sensors that are measuring environmental variables, and record the information along with the AE data. These are called " parametric inputs". Wind gauges, strain gauges and weight-in-motion systems can be used to provide parametric input to the AE system. Often the system allows the data from these sensors to be taken at regular time intervals even in the absence of AE; this is called " time –driven data" in contrast to the " hit-driven" AE data.

Parametric inputs were first introduced into AE systems in order to record slowly varying, controlled stimuli such as the pressure during the proof test on a pressure vessel. The same parametric input can also be used to record the dynamic, uncontrolled stimuli of traffic and weather loading on bridges. However, the nature of the dynamic data is much more complex and the task of correlating stimulus and response is not straightforward.

## 1.7 The AE Measurement Chain:



The AE measurement chain.

The diagram in figure above shows the schematic of an AE measurement chain, from the couplant up to the PC.

### 1.7.1 The Couplant:

The coupling agent is crucial to the quality of sensor coupling. It shall provide a good acoustic contact between the sensor and the surface of the test object. Make sure to select the appropriate couplant, which does not corrode the test object's surface, and which fits to the given temperature.

Couplant should have the following characteristic:

i. High wettability
ii. Corrosion resistance
iii. Sufficient viscosity (high)
iv. Easy remover
v. Low attenuation
vi. Good acoustic impedance with test piece and sensor

Some commonly used Couplants are:

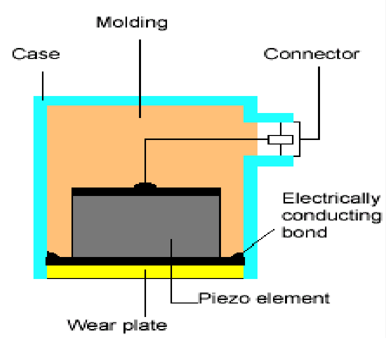
i. Natural wax
ii. Silicon grease
iii. Epoxy resin
iv. propylene glycol
v. Honey

**Note:** Some of the glues become brittle and produce strong cracking noise with smallest movement of the test object! Therefore it is recommended to glue an elastic sensor hold down at the sample and to fix the sensor with an elastic device, e.g. a rubber band, against the test object's surface.

For best coupling results, do not take too much of the couplant and make the layer as thin as possible by firmly pressing the sensor against the test object's surface. After attaching the sensor(s), the quality of the coupling must be verified (pencil lead break, automatic coupling test). If required, the coupling procedure must be repeated.

### 1.7.2 Acoustic Emission Sensors:

#### 1.7.2.1.



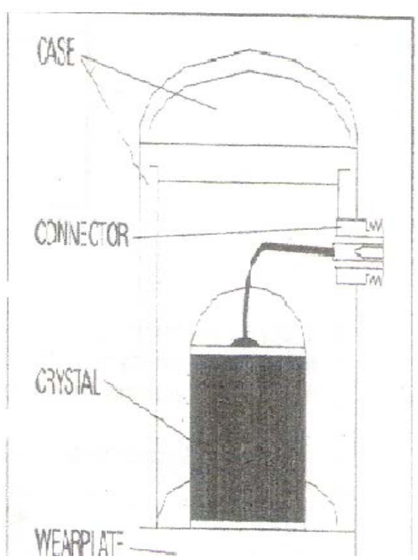
Basic setup of an AE sensor.


AE sensor with integrated pre-amplifier.

**Sensor** is the heart of any AE system. The selection of an AE sensor (transducer) is most important factor in AE testing. Sensors actually "listen" to structures and materials to detect AE activity. These are vital links between directly linked critical to the success of every test.

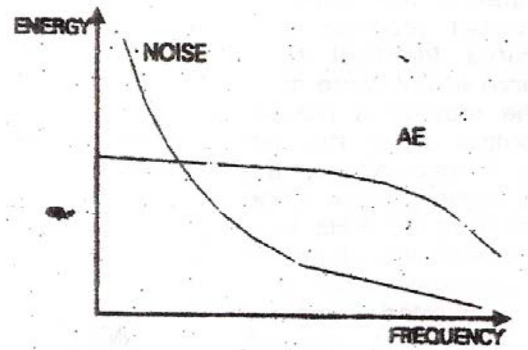
**1.7.2.2** For sensing AE waves Piezoelectric crystals are used. The Greek word 'Piezein' means 'to squeeze'. These are special materials that generate an electrical voltage and corresponding separation of charge when they are squeezed (deformed). In the AE sensor, the deformation is produced by motion. It is the elastic response of the piezoelectric crystal mounted inside the sensor enclosure as illustrated in the figure. An ideal sensor would produce a voltage – time curve identical to amplitude – time curve of the wave at the point where the sensor is placed. Electrical signal output from the AE sensor is strongly influenced by the characteristic of the sensor. Usual range of AE sensors vary from 30 KHz to 2 MHz, depending upon the type of the application and components under test. In order to send converted electrical signals to larger distance through cables, the sensors are provided with preamplifiers so that signals may not die out before reaching to data acquisition system. The sensors with in build preamplifiers are specifically engineered to attain high sensitivity and the capability to drive through long cables without the need for separate preamplifier. The elimination of separate preamps, cables and vulnerable connectors greatly improves the reliability in tough environments and significantly reduces set up time. Integral preamp sensors incorporate a low – noise FET input, 40 dB preamplifier and a filter all inside stainless steel housing. A sensor's response during a test can be predicted by its frequency response, they operate at specific range of frequencies. 30 KHz ( R 3I ) & 60 KHz ( R 6I ) resonant frequencies or wide band are usually suited for concrete and, 150 KHz ( R 15I) , 300 KHz ( R 30I ) range are suitable for monitoring of steel structures. Optional Auto Sensor Test (AST) capability allows the sensors to pulse as well as receive. The features allow users to verify sensor coupling and performance at any time throughout the test.

**1.7.2.3** These sensors are completely enclosed in stainless steel casings. Care has also been taken to thermally isolate the critical input stage of the preamplifier in order to provide excellent temperature over the range of – 45 $^{O}$ to + 80 $^{O}$ C.



#### 1.7.2.4 Sensors Choice & Mounting:

- The specification of the sensor and its subsequent performance are considered by its sensitivity, operating frequency and band width. Resonant sensors are useful as they are more sensitive to AE sensor; this is clearly advantageous if sensor spacing is to be maximized to reduce equipment requirements and cost, however,




more spacing of the sensors reduces the sensitivity of AE signals as shown in figure given below. Resonant AE sensors are available with a variety of resonant frequency, ranging from 30 KHz to 1000 KHz as the frequency raised the spectrum of typical background noise falls off more rapidly than the spectrum of AE waves impulses as shown in the figure. The commonly used sensors and their specifications are as follows;

| **Resonant Sensors Type** | **Suitable Frequency range** | **Desirable spacing in mm** |
|---|---|---|
| R 3 I | 20-40 KHz | 1000 – 1200 |
| R 6 I | 40 – 100 KHz | 1000- 1500 |
| R 15 I | 70 – 200 KHz | 3000-4500 |
| R 30 I | 125-450 KHz | 3000-5000 |

- A range of options for sensor mounting and attachment exist, the choice of which primarily depends on the test duration and bridge properties and environment. In short term test on a steel structure, a conventional magnetic clamp and fluid couplant will suffice. However, if the site is exposed to the elements, this may result in the degradation of the structure/sensor interface. It is vital that the surface of the structure is carefully prepared as AE signals cannot be expected to penetrate loose layers of paint, corrosion or insulation and care must be taken when mounting a sensor to choose an area relatively free of deep surface pitting or other minor imperfections. Such imperfections, if excessively ‘deep’, results in poor intimacy between the sensor and structure.

### 1.7.2.5 Selection of sensor for particular test should be taken as under :

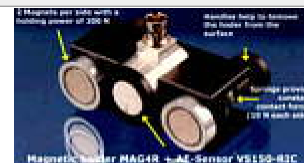
| Type of Structure | Type of sensor |
|---|---|
| 1.Steel structure | |
| a) For Small Area | R30 I |
| b) For Large Area | R 15 I |
| 2.Concrete structure | |
| a) For Small Area | R 6 I |
| b) For Large Area | R 3 I |
| | |

### 1.7.3 Attachment of the Sensors:

Usually, AE sensors are attached to the test object using magnetic holders (see figure). With non-magnetic objects, elastic ties, tape, clamps, glue, etc are used.

When attaching sensors, please take care to avoid unwanted noise produced by loose parts, striking cables, etc.

During the whole measurement, a constant hold-down force must be ensured.



Magnetic holder including sensor

**AE Preamplifier:**

**1.7.4** The AE preamplifier can be either a separate device or is integrated into the sensor. It amplifies the AE signal and drives the cable between sensor and AE system. Important characteristics:

- Low input noise to distinguish smallest sensor signals from electronic noise
- Large dynamic range to process high amplitudes without saturation
- Large range of operating temperature for applications in the neighborhood of low temperature vessels as well as above the transition temperature from brittle to ductile behavior
- Usual voltage supply: 28 V DC via signal cable
- Optional frequency filter

**1.7.4.1** Sensors R3 I, R6 I, R15 I, R30 I, and R50 I integral preamplifier is of low noise FET in put 40 dB pre-amplifier inside a standard high sensitivity sensor. These rugged , small size AE integrated preamplifier / sensors eliminate the need for cumbersome preamplifier by incorporating two functions into one, thereby reducing equipment cost and decreasing set up time for field application . These sensors also come with optional “ Auto Sensor Test” capability designated with an “AST” suffix after the sensor model type (e.g.R15 I –AST). AST models offer an internal sensor pulsing capability when used with A or AST capable AE systems with the AST capability such as MISTRA or SPARTAN 2000. AST provides an automated means of pulsing and receiving a simulated AE bust that is coupled to the structure. AST tests the entire AE signal processing chain starting with the sensor coupling, through the sensor and preamplifier, cabling and AE system electronics. This is useful for testing individual sensor coupling, verifying the response of other sensors attached nearby to the same structure, establishing inter-sensor timing parameters that can be used to determine sensor spacing and providing verification of the repeatability of the AE sensors throughout the AE test.

These integral pre-amplifier sensors were developed with the purpose of attaining high sensitivity and the capability of driving long cables without the need of a separate pre-amplifier. In addition, they connect directly to all existing PAC AE instruments and systems and are also compatible with other manufactures systems.

Features:

- Small size, stainless steel construction
- Operation range – 45 $^{o}$C – 80 $^{o}$C ( -25$^{o}$C -80$^{o}$C for AST versions)
- Good RFI/EMI immunity
- Wide dynamic range ( > 80 dB)
- Low noise pre-amp ( -2 u V )
- Single BNC input/ out put ( power signal)
- Interchangeable with existing pre-amp/sensors
- Ideal for field / lab testing.
- Auto Sensor Test option allows for sensor pulsing or self – test.

Functional Description :

The integral sensors are completely enclosed in a stainless steel case and coated to minimize RFI/EMI interference. In addition, care has been taken to thermally isolate the critical input stage of the pre-amplifier, in order to provide excellent temperature stability over the range of -45 $^{o}$C to + 80 $^{o}$C. For ease of use, the integral sensors utilize a standard coaxial cable with BNC connector to power the pre –amp and carry the output signal. The complete schematic of the integral sensor is shown in fig. 1

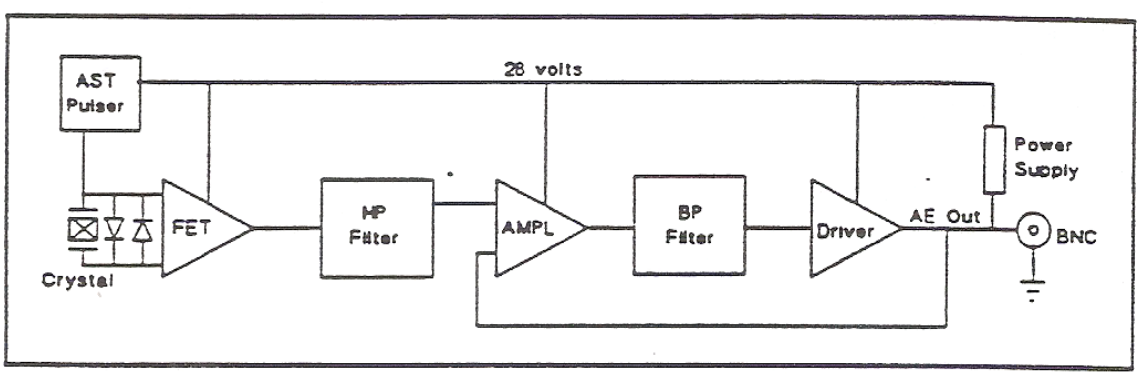



Fig. Integral Sensor Block Diagram

**Specification :**

| | |
|---|---|
| Gain | 40 $\pm$ 1 dB |
| Peak Sensitivity | 30 dB re 1 V/u Bar |
| Noise ( RMS rti) | - 2 uV |

| | |
|---|---|
| Dynamic Range | > 80 dB |
| Output voltage | >15 Vpp into 50 ohms |
| Power Required | 28 V at 20 mA |
| AST pulse | -24 V , 4 microseconds into crystal |
| AST Trigger | < 2 Volts at sensor input |
| Completely enclosed crystal for RFI/EMI immunity. | |

**Physical Specification :**

| | |
|---|---|
| Temperature ( o C) | -45 to +80 ( -25 -80 for AST) |
| Shock limit (g) | 500 |
| Case material | Stainless steel ( 304) |
| Face material | Ceramic |
| Grounding | Case grounded and isolated from mounting surface |
| Connector type | BNC |
| Connector location | Side (TC option provides a Top mount connector) |
| Directionality(dB) | ± 1.5 |
| Seal type | Epoxy |
| Pressure | < 400 psi hydrostatic pressure |

| Model Related Specification | Sensor Model | | | | |
|---|---|---|---|---|---|
| | R6 I | R15 I | R30 I | R50 I | WDI |
| Sensor drive capability (w/RH-58 AU cable) | Upto 3000 ft. (1000 m) | Upto 1000 ft. (300 m) | Upto 500 ft. (160 m) | Upto 300 ft. (100m) | Upto 300 ft. (100 m) |
| Dimensions (dia. x ht (mm) | 29x40 | 29x31 | 29x31 | 29x30 | 29x30 |
| Dimensions ( dia. x ht (m) | 1.13x1.6 | 1.13x1.23 | 1.13x1.23 | 1.13x1.16 | 1.13x1.16 |
| Wight ( gm) | 98 | 70 | 75 | 70 | 70 |
| Peak sensitivity Ref V/m/s)/[Ref V/mbar] | 120† [-26]* | 109† [-24.5]* | 98† [-24]* | 86† [-28]* | 87† [-28]* |
| Operating frequency range ( kHz) | 40-100 | 70-200 | 125-450 | 300-550 | 100-1000 |
| Resonant frequency ( kHz)1 | 50† [90]* | 125† [153]* | 225† [350]* | 320† [500]* | 125† [500]* |

Note : † Denotes response to plane waves ( range to incidence normal to face of sensor).

* Denotes response to surface waves ( angle to incidence transverse or parallel to face of sensor)

The AE preamplifier can be either a separate device or is integrated into the sensor. It amplifies the AE signal and drives the cable between sensor and AE system. Important characteristics:

- Low input noise to distinguish smallest sensor signals from electronic noise
- Large dynamic range to process high amplitudes without saturation

- Large range of operating temperature for applications in the neighborhood of low temperature vessels as well as above the transition temperature from brittle to ductile behavior
- Usual voltage supply: 28 V DC via signal cable
- Optional frequency filter
- Calibration pulse can be routed through to the sensor

### 1.7.5 Preamplifier to System Cable:

- Coaxial cable, usually RG 58 C/U
- 50-Ohm BNC connectors at both ends
- May have a length of several 100 m
- Transmits AE signal, DC power supply, and calibration pulse for sensor coupling test

### 1.7.6 Frequency Filter:

The frequency filter is used to eliminate unwanted frequency ranges (noise sources) and matches the measurement chain to the requirements of the application.

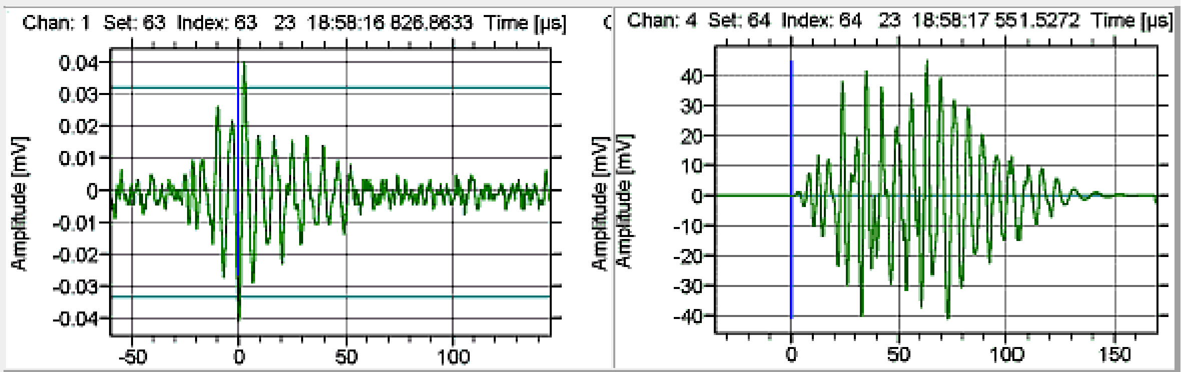
- 20 - 100kHz for tank bottom tests (leakage, corrosion)
- 100-300kHz for integrity testing metallically components
- Above 300kHz for reduced range (smaller distance between sensors).

Filter modules are easy to exchange. Optionally, the wanted frequency range can be selected via the software in order to match the system with the requirements in the field without changing the measurement electronics (e.g. for easy switching between tank bottom and integrity testing).

### 1.7.7 The A/D Converter:

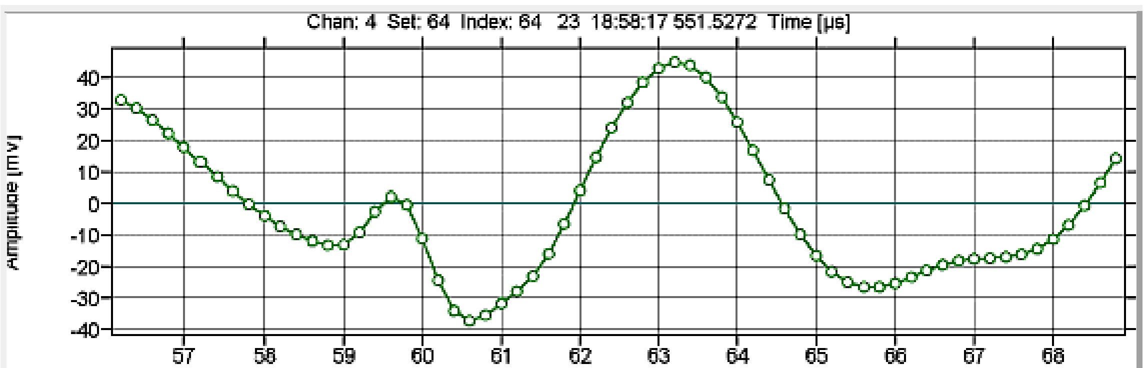
The A/D converter is used to digitize the AE signal that has passed the frequency filter. A huge measurement dynamic is required, as very strong bursts from nearby produce much higher amplitudes than weak ones from a big distance.

This shall be illustrated by figure below. The demand on the complete measurement chain and especially on the A/D-converter, with respect to dynamic range and sample rate is enormous: Signals from weak sources in large distance shall be discriminated from the electronic noise and signals from strong sources in short distance must not saturate the measurement range. Thanks to the progress in microelectronics, such demands became feasible during the most recent years. Figure 13 shows a low and a high amplitude signal, as it was digitized by the AE-System in the measurement range of +/-100mV. The left signal shows burst amplitude of about 40□V, the right one of about 40 mV, a 1000 time's higher amplitude.




AE signal dynamics - bursts with amplitudes of 40µV (left) und 40mV (right).

The AE technique puts high demands not only on the dynamic range, but also on the measurement speed. In order to e.g. derive the maximum amplitude directly from the samples of the A/D converter (ADC) quickly and without extensive calculation processes, even the interesting signal frequencies between 100 – 300 kHz require a sample rate of 5 – 10 MHz. Figure below shows the section of the waveform in figure 13 (right) with the maximum amplitude at 63.2µs. Each sample is displayed as a bullet. There are 5 bullets eachµs, so, the curve was stored with a sample rate of 5 MHz. With half the sample rate, the measurement point at 63.2µs would be missing, producing an additional measurement error of some percent. If the sample at 59.6µs would be missing, the number of threshold crossings would be too low by one, as only this sample exceeds the positive threshold (at 32µV).




Section of the maximum amplitude at 63.2 µs. Bullets correspond to measured values at a sample rate of 5 Msamples/second.

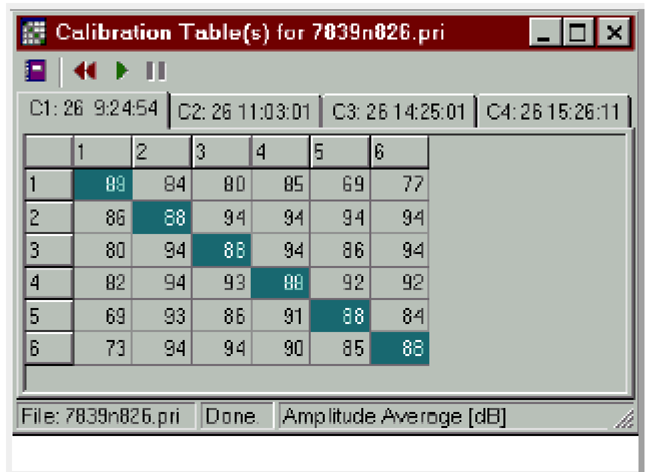
### 1.7.8 Personal Computer and Software:

Modern AE systems use computers providing a menu-driven parameter input and system control. An online help system provides quick access to help texts explaining the use of the software.

First the result of a data acquisition is just a file containing the features of all the bursts of all the sensors as well as the external parameters, such as test pressure, temperature, and others. If the complete waveform is to be stored, another file is created. During the test the measured data is online analyzed and displayed, so the operator may immediately recognize the possible development of defects within the test object. He may then halt the load increase (e.g. pressurization at pressure tests) in order to minimize possible danger to man, environment, and the tested object.

The tasks of the PC are:

- Data acquisition and storage (all data are stored)
- Data analysis, online / offline
- Logical filtering (plausibility)
- Location calculation and clustering
- Statistics
- Display of the results (graphically and numerically)
- Self test of the system hardware
- Sensor coupling test, recording of the sensor frequency response.




| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| 1 | 89 | 84 | 80 | 85 | 69 | 77 |
| 2 | 86 | 88 | 94 | 94 | 94 | 94 |
| 3 | 80 | 94 | 88 | 94 | 86 | 94 |
| 4 | 82 | 94 | 93 | 88 | 92 | 92 |
| 5 | 69 | 93 | 86 | 91 | 88 | 84 |
| 6 | 73 | 94 | 94 | 90 | 85 | 88 |

**1.7.9 The Sensor Coupling Test (also referred to as auto-calibration):** Using this function the coupling of the sensors can be checked automatically.

One channel transmits an electrical test pulse to the connected sensor. This sensor emits a mechanical wave, which is detected by the neighboring sensors. After 3 test pulses, the next sensor becomes the pulse emitter. The plausibility of the received amplitude allows to draw conclusions on the quality of the coupling.

The table on the right shows a sensor coupling test with 6 channels.

Sample reading: Row 6, column 1: value 73dB

The value of 73dB means that the wave emitted by channel six had 73 dB amplitude when arriving at channel 1.

The automatic coupling test is performed before and after the test in order to prove a constant quality of the coupling.

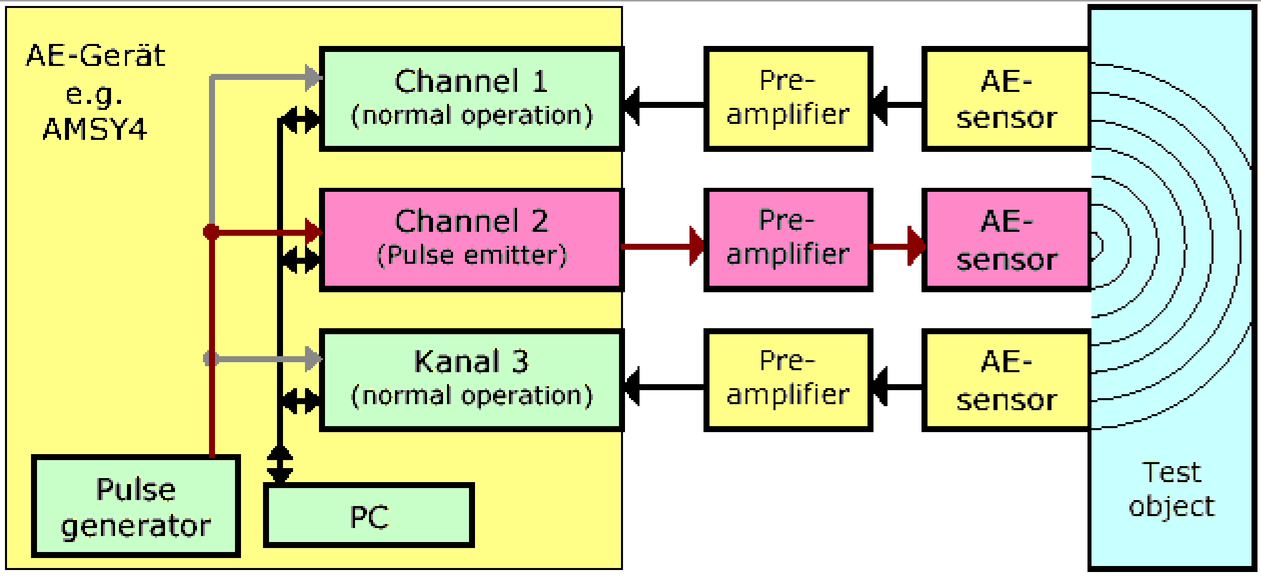
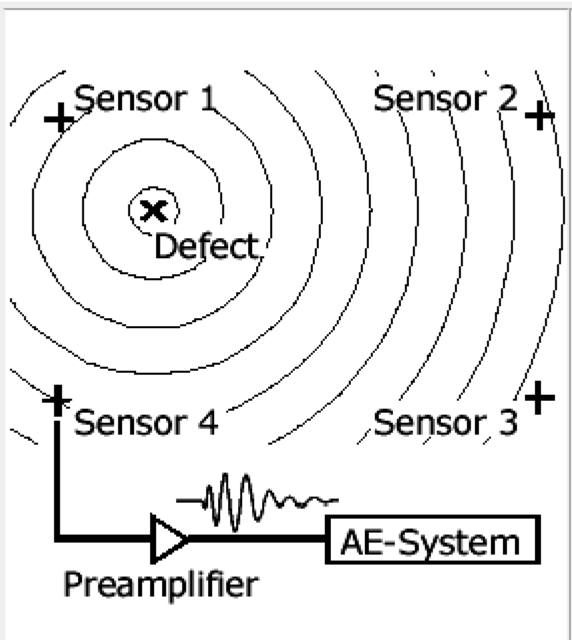



Diagram of the automatic sensor coupling test.

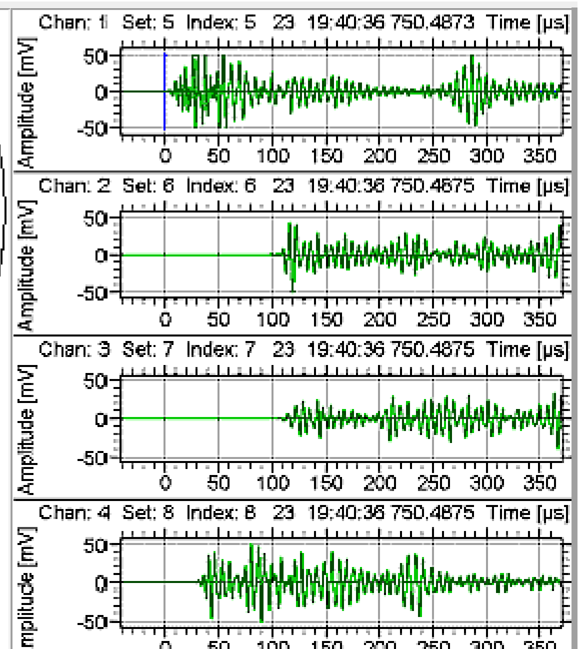
## 1.8 Location Calculation and Clustering:

### 1.8.1 Location Calculation Based on Time Differences:

The determination of the source location of each event is an essential element of AE testing. The distance difference between a source (defect) and different sensors are equal to *Arrival Time Difference * Sound Velocity*. Location calculation is based on the evaluation of the arrival time differences of the AE signal propagating from its source to different sensors as illustrated in the two-dimensional example shown in Figure below. An AE wave is propagating in concentric circles from its source and arrives at different sensors with certain delays. The delay is proportional to the distance between the sensor and the source. In this example the wave first reaches sensor 1, then 4, 2 and, at last, sensor 3.

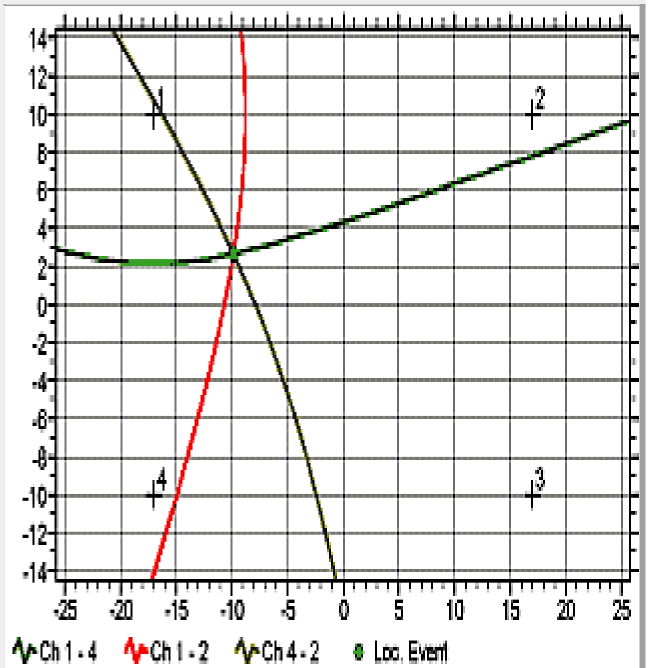



The principle of localization.




Sensor signals.

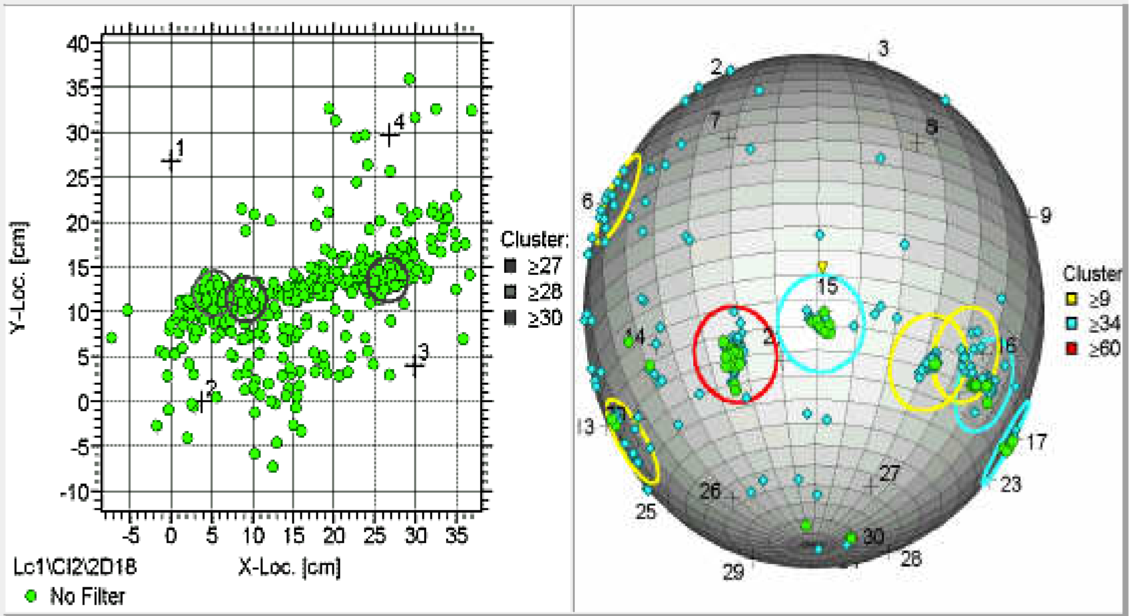
In figure above the waveforms of a breaking pencil lead on an acrylic glass plate with four sensors, configured similar to figure above, are displayed. The zero of the time axis marks the arrival time at the sensor 1 that was hit first in this example. The arrival time differences between channel 1 and the channels 2, 3, and 4 can be read at the time axes of the waveform diagrams.




Hyperbola intersection with 3 hit sensors.

All points having a constant difference between their distances to two fixed points form a hyperbola. Figure below shows three hyperbolae, each representing all points with the calculated distance difference to two sensors. At the point of intersection of the three hyperbolae, the three distance differences are equivalent to the measured time differences. So, this is the wanted source position. As can be seen in this example, the arrival time at three sensors is required to find the point of intersection. If an AE event only arrives at two sensors, there is only one couple of sensors and, thus, only one hyperbola, which is not sufficient for this method to calculate the planar location. Hyperbola diagrams (like in figure below) are mainly used to check the plausibility of certain selected location results. Mostly, the calculation is based on an inverse method, which, in addition to the location results, provides a measure of the reliability of the location calculation, if more than three sensors have been hit by the event.

Usually, the results of a location calculation are plotted in a point diagram without the hyperbolae, but including the positions of the sensors, as shown in figure below. The data of figure below have been recorded during the compression of a 5 cm thick glass foam plate producing a huge number of events. Accordingly, it is quite difficult to find locations in the diagram with highest location density, as we can't see how many points are overlaying. Usually, the AE technology uses the so-called ***clustering*** in order to clearly mark off those areas of high location density.

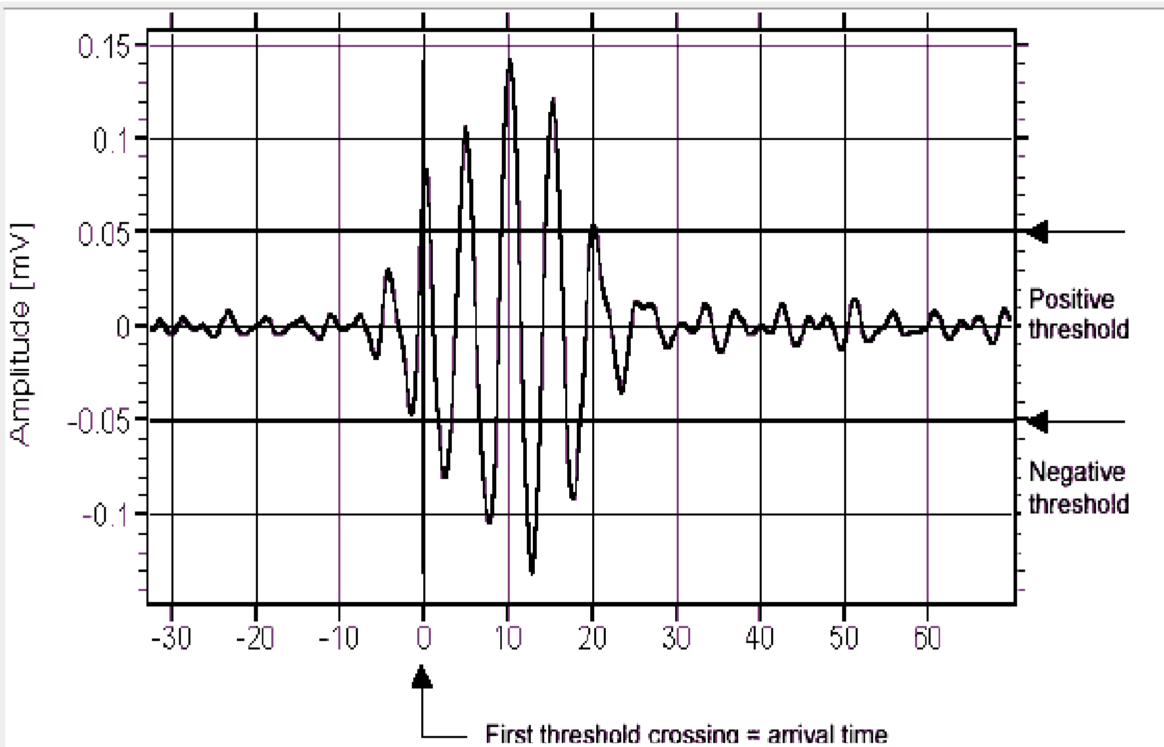


Location and clustering charts.

### 1.8.2 Determination of the Arrival Time:

One of the very important tasks of AE systems is to convert the AE bursts into compact data sets and to eliminate the background noise (which is more or less continuous).

For this, modern AE systems use detection thresholds. The threshold has to be set to the right value by the user. If the AE signal exceeds the threshold in either positive or negative direction, this means the start of a hit (a hit is a detected burst).



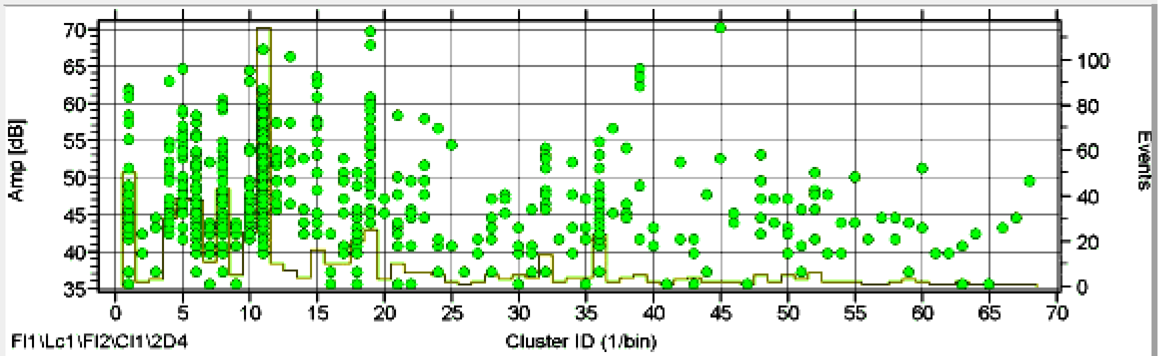
Determination of the arrival time.

The time of the first threshold crossing is called “arrival time of the burst” and is needed for location calculation.

Waveforms like in figure given above are produced by joining many single points called ‘samples’. They correspond to single measurements at constant time intervals. Digital systems sample the AE signal e.g. every 100 ns, which means 10 million times a second. The unit of the time axes of the above diagrams is µs, i.e. every 10 µs interval contains 100 samples. A wave packet of 100 µs as shown above is made of more than 1000 samples, which shows the huge amount of memory required for a single burst.

### 1.8.3 Clustering:

Clustering is a mathematical method used to determine the point density within a certain area, marking those areas of high point density by colored rectangles or circles. The left diagram of figure above shows three clusters, so, three areas of high point density where found. The clusters are marked by colored circles, the color indicating the number of elements within the cluster. In addition to the planar location, other location algorithms are required, such as the location on a sphere surface (spherical location calculation) providing a 3-dimensional rotating display of the sphere shown on the right of figure above. Even here, clustering is required and possible. Spherical liquid gas and natural gas tanks are important test objects where the application of AE testing could prove its capability in many cases.



Amplitude and number of event vs. the cluster ID.

The display of results as shown in figureabove is of special interest with respect to location clusters. The horizontal axis shows the cluster ID. The vertical axis on the left scales the amplitude points and the vertical axis on the right displays the number of events per cluster indicated by the stepped line. This diagram clearly shows the tester even during the test whether location clusters with high numbers of events and relevant amplitudes are forming. He can see immediately whether new, located defects develop. Looking at the diagram above, cluster no. 11 contains about 105 events (see right scale) with amplitudes of 39 to 67 dB (see left scale).

### 1.8.4 Location Errors:

Compared to the early days of AE testing, nowadays an excellent location technique is available to the AE tester. Anyway there is still room for improvements to be developed. Today, the AE tester himself has to take care of influences causing location errors and rate them in a correct way.

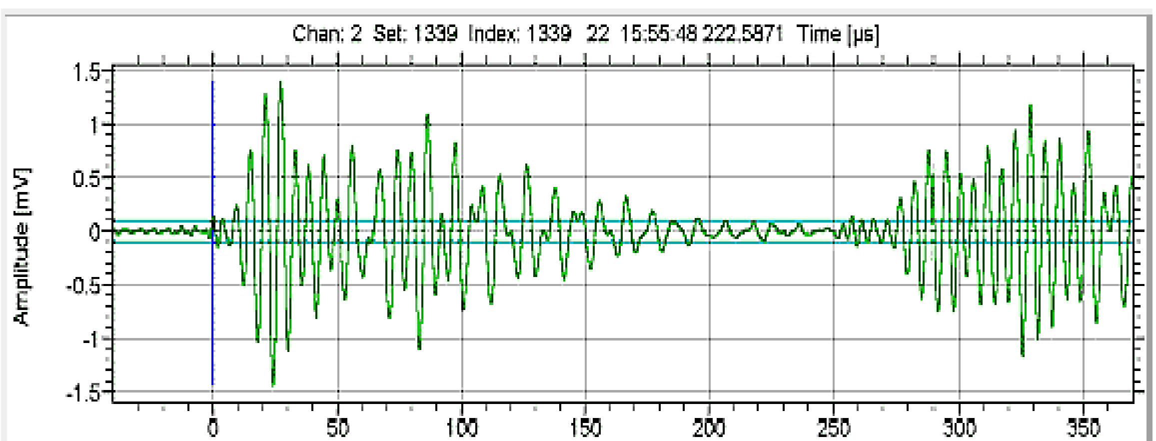
Some of the influences on the location accuracy are:

- A different wave mode than the assumed one determines the arrival time
- A wave takes a different propagation path than assumed by the algorithm
- Multiple waves overlap at the sensor
- Sources emit signals in such a quick succession, that there is not enough time for the signals in the structure to decay, therefore do not represent a "new" hit.

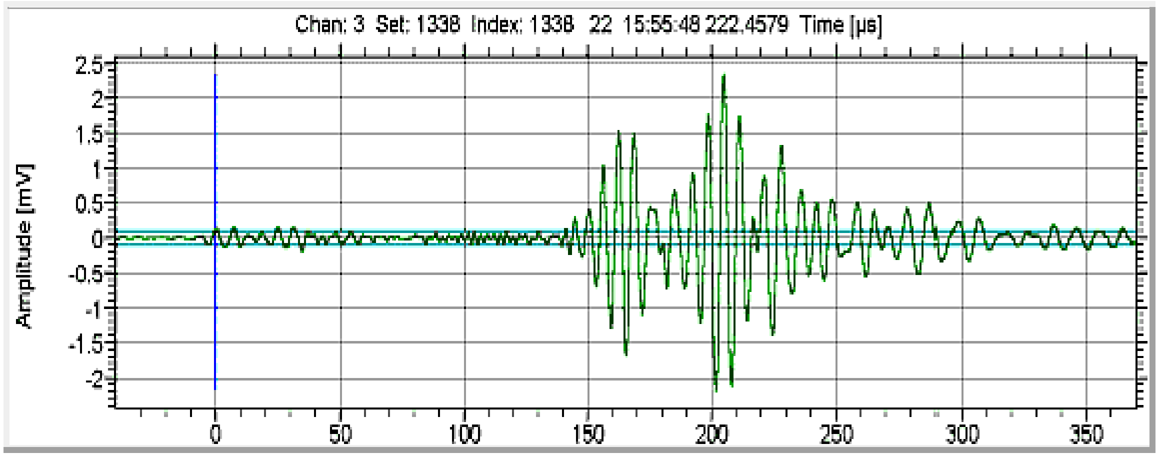
One of the problems is, that from the AE signal one can't know whether it was produced by a real defect and, if so, how big e.g. the crack growth was. One has to build up know-how by investigating the emission behavior of materials by tensile tests in the laboratory. Doing so, one has to consider, that e.g. the propagating conditions for mechanical waves in real test objects and small samples are different. All these aspects may make the un-experienced feel uncertain about the AE technology. But the theoretical and practical knowledge of the AE behavior of materials and structures increases steadily.

Figure below illustrates a typical cause for location errors. The upper waveform (channel 2) has exceeded the threshold (the 0.1 mV lines) for the first time by a wave mode (t = 0), which produces the highest amplitude at 25 µs. This wave mode propagates with about 3.2 m/ms. Channel 3 (lower waveform) has received a stronger signal (the sensor of channel 3 was a little closer to the source). Here, the threshold was first crossed (t = 0) by a 'predecessor' signal. The predecessor is a faster wave mode propagating with a speed of about 5 m/ms. The time of the first threshold crossing of the wave mode propagating with 3.2 m/ms at channel 3 is found at about 140 µs. So, the arrival time of the lower waveform is 140 µs too early, if the location algorithm uses a speed of 3.2 m/ms. Hence the distance difference between the source and the channels 2 and 3 is calculated by 0.5 m (0.14 ms * 3.2 m/ms) too small, producing a considerable location error. As the example of these two waveforms shows, the determination of the arrival time by the first threshold crossing is quite problematic.

We have to be especially aware of location errors if there is inhomogeneous wave propagation, which e.g. is the case close to manholes, nozzles, etc. Materials with anisotropic wave propagation do not allow for precise location.

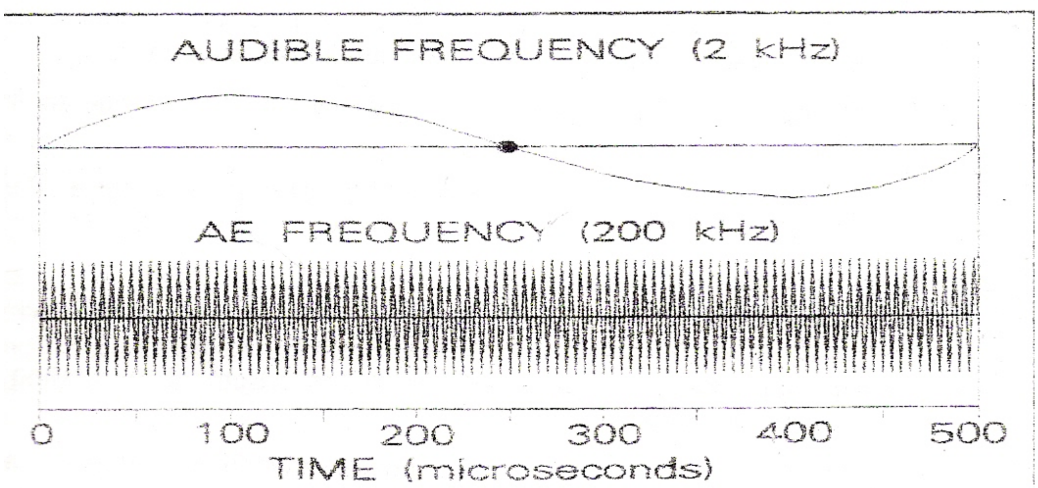



Location error caused by the acquisition being triggered by different wave modes. Top: a0, bottom s0.




## 2.0 DIFFERENCES BETWEEN AE AND AUDIBLE SOUND:

AE signals and more familiar audible sounds have different source characteristics and different transmission characteristics. The first reason is that they are different part of Acoustic spectrum. Typical AE frequencies are almost100 times higher than the frequencies best heard by the human ear as shown in fig given below.




Often a source that is easily heard by the ear does not put out enough high frequency energy to be detected by an AE sensor and vice-versa. A near by thunder clap might deafen the ear. But an AE system will not detect it; a pin dropped makes little sound but delivers high amplitudes signals to an AE system. The second main reason that human ears detect air borne signals but the AE sensors detects the movement in the solid material of the bridge.

## 3.0 DATA ACQUISITION SYSTEM AND OTHER ACCESSORIES:

The most common design of AE instruments is working on hit base system. Typical AE activity consists of a series of distinct signals. These signals emitted at random time intervals and have varying shapes and sizes.

To meet requirement of storage of AE signals at high rate and analysis, filtering of same, multi channel data analysis, a dependable data acquisition system is must. RDSO has procured two sets of AE equipment from M/S Physical Acoustics ltd. U.K for study of AE technology for application on Railway Bridges.

1. MISTRAS 2001 (Massively Instrumented Sensor Technology to Received Acoustic Signals)

2. SPARTAN 2000 (Source position and real time analysis)

### 3.1 Mistras 2001:

It is a fully digital, multi channel computerized AE system that can performs AE waveform and signal measurements and stores, displays and analyses the resulting data. The main component that makes up a MISTRAS system consists of an IBM compatible, personal computer (PC), printed circuit board (cards), the MISTRAS software. This system is much more powerful than SPARTAN with many increased features like waveform analysis, increased sampling rate, high speed for acquisition AE signals (of the order of 15000 hits per second ) , 3D analysis etc. The system is better suited for mounting concrete bridge and for R &D purposes. The detailed specification of this system is placed as Annexure-A.

### 3.2 Spartan 2000:

It is a computerized AE system that performs AE signal measurements using industry standard features extraction technique as well as waveform processing and stores, displays and analyses the resulting signals and data in graphic form. This system is well suited for preliminary investigation and for steel structures. It is not desirable to use it for monitoring of concrete structures. The system performs well in all test environments. It is $4^{th}$ generation of industry-hardened instruments time tested and proven in harsh industrial testing environments throughout the world. It is capable of handling more than 128 channels of AE. It provides very simple and users friendly system to detect and locate structural flaws in variety of materials. Today majority of the field test are performed using this system. The detailed specification of this system is placed as Annexure – B.

## 4.0 ACOUSTIC EMISSION CODES AND STANDARDS

**American society for testing and materials (ASTM)**

| | | |
|---|---|---|
| 1 | E569-85 | Standard practice for AE monitoring of structures during controlled stimulation. |
| 2 | E610-82 | Standard definitions of terms relating to acoustic Emission |
| 3 | E650-85 | Standard guide for mounting Piezoelectric acoustic emission sensors |
| 4 | E749-80 | (Reapproved 1985) Standard practice for acoustic emission monitoring During Continuous Welding. |
| 5 | E 750-80 | Standard Practice for Measuring the Operating Characteristics of Acoustic Emission Instrumentation |
| 6 | E-751-80 | Standard Practice for Acoustic Emission Monitoring During |

Resistance spot –welding.

| | | |
|---|---|---|
| 7 | E 976-84 | Standard Guide for Determining the Reproducibility of Acoustic Emission Sensor Response. |
| 8 | E 1002-84 | Standard Method of Testing for Leaks Using Ultrasonics |
| 9. | E 1067-85 | Standard Practice for Acoustic Emission Examination of Fiberglass Reinforced Plastic Resin (FRP) Tanks/Vessels. |
| 10 | E 1106-86 | Standard Method for Primary Calibration of Acoustic Emission Sensors. |
| 11 | E 1118-86 | Standard Practice for Acoustic Emission Examination of Reinforced Thermosetting Resin Pipe (RTRP) |
| 12 | F 914-85 | Standard Test Method for Acoustic Emission for Insulated Aerial Personnel Devices. |

**AMERICAN SOCIETY OF MECHANICAL ENGINEERS (ASME)**

| | | |
|---|---|---|
| 13 | | "Proposed Standard for Acoustic Emission Examination During Application of Pressure", E00096(1975) |
| 14 | | "Use of Acoustic Emission Examination in Lieu of Radiography", code case No. 1968, Section VIII, division 1 (1982) |
| 15 | | "Acoustic Emission Examination of Fiber-Reinforced Plastic Vessels," Article 11, Subsection A, section V, Boiler and Pressure Vessel Code (1983 and latter editions). |

**UNITED STATES DEPARTMENT OF TRANSPORTATION (DOT)**

| | | |
|---|---|---|
| 16 | E8944: | Code Variance (Tube Trailer Testing) |

**THE SOCIETY OF THE PLASTIC INDUSTRY (SPI), REINFORCOED PLASTICS / COMPOSITES INSTITUTE**

| | | |
|---|---|---|
| 17 | | "Recommended Practice for Acoustic Emission Testing of Fiberglass Tanks / vessels" (1982), revised 1987) |

**THE JAPANESE SOCIETY FOR NDI (NDIS)**

| | | |
|---|---|---|
| 18 | | NDIS 2412-1980 " Acoustic Emission Testing of Spherical pressure Vessels Made of High Tensile Strength Steel and Classification of Test Results. |

**THE EUROPEAN WORKING GROUP ON ACOUSTIC EMISSION (EWGAE)**

| | | |
|---|---|---|
| 19 | | EWGAE codes for Acoustic Emission Examination : code I Vessel Inspection |
| 20 | | EWGAE Codes for Acoustic Emission Examination: Code II –Leak Detection. |

| | | |
|---|---|---|
| 21 | | EWGAE Code for Acoustic Emission Examination Code III – Examination of small Parts. |

**ISO STANDARDS**

| | | |
|---|---|---|
| 22 | ISO12714:2001 | Non-Destructive Testing Acoustic emission inspection – secondary calibration at acoustic emission sensors |
| 23 | ISO12713:1998 | Non-Destructive Testing Acoustic emission inspection – primary calibration at acoustic emission sensors |
| 24 | ISO12716:2001 | Non-Destructive Testing Acoustic emission inspection – vocabulary. |

**INDIAN STANDARDS SPECIFICATION**

| | | |
|---|---|---|
| 25 | IS12170-1989 | Glossary of terms used in AET |

## 5.0 REFERENCES:

**(A) Details of RDSO Reports on Bridge tested using Acoustic Emission Technology**

| S.No | Br. No | Section | Railway | Type of Bridge | Span (m) | BS-Report |
|---|---|---|---|---|---|---|
| 1. | 65 | Godhra-Anand | W.R | Open web girder | 17 x 45.7 | BS-54 |
| 2. | 226 UP | Ratlam-Godhra | WR | -do- | 6x45.7 + 1x30.5 | BS-54 |
| 3. | 88 | Singrauli- Obra | ECR | PSC | 3x24.4 | BS-62 |
| 4. | 73 | Bhayandar - Virar | WR | PSC Box girder | 1x20 + 28x48.5 | BS-71 |
| 5. | 78 | Sonpur-Hazipur | ECR | Plate girder | 8x76.2 +5x18.3 | BS-72 |
| 6. | 248A | Vijaywada - Vishakhapattan | SCR | Bow String Twin Arch Bridge PSC Box girder br. | 28x97.552 | BS-81 |

**(B) Other References:**


1. Pollock, A. A., Acoustic Emission Inspection, Metals handbook Ninth Edition, Volume 17, pages 278-294, ASM International 1989.

2. Harris, D.O., and Dunegan, H.L., “Continuous Monitoring of fatigue Crack Growth by Acoustic Emission Techniques”, Experimental Mechanics, 14, 2, 71, 1974.

3. PAC’s Recommended Test Method for AE Instrument Performance Verification, PAC-RTM-1, Physical Acoustic Corporation, Princeton, NJ, 1991.

4. PAC’s Recommended Test Method for Verifying the Consistency of AE Sensor Response, PAC-RTM-2, Physical Acoustic Corporation, Princeton, NJ, 1991.

5. Carlyle, J.M., and Ely, T.M., Acoustic Emission Monitoring of the I-95 Woodrow Wilson Bridge, Phase Report, Contract DTFH61-90-C-0049, Federal Highway Administration, Washington, DC, September, 1992.

6. Carlyle, J.M., and Leaird, J.D., Acoustic Emission Monitoring of the I-80 Bryte Bend Bridge, Phase report, Contract DTFH61-90-C-0049, Federal Highway Administration, Washington, DC, October, 1992.

7. Carlyle, J.M., Acoustic Emission Monitoring of the I-10 Mississippi River Bridge, Phase Report, Contract DTFH61-90-C-0049, Federal Highway Administration, Washington, DC, January, 1993.

8. Carlyle, J.M., Acoustic Emission Monitoring of the I-205 Willamette River Bridge, Phase Report, Contract DTFH61-90-C-0049, Federal Highway Administration, Washington, DC, April, 1993.

9. Dunegan Corporation, Acoustic Emission Monitoring of Electroslag and Butt Welds on the Dunbar Bridge, Final Report, West Virginia Dept. of highways, August, 1984.

10. Hopwood, T., Long-term Evaluation of the Acoustic Emission Weld Monitor, Report No.FHWA-TS-88-021, February, 1988.

11. Detection of Active defects on Steel and Concrete Specimen in Application of Acoustic Emission Technique on Railway Bridges- Laboratory (progress report No. 1)-March, 2001,B&S Directorate, RDSO, Lucknow.

12. Application of Acoustic Emission Technique on Railway Bridges- Study of Crack Growth in Steel Specimen (progress report No. 2)-March, 2001,B&S Directorate, RDSO, Lucknow.

13. Application of Acoustic Emission Technique on Railway Bridges- Study of Effect of Different Noise Signals on AE Parameters (progress report No. 3)-June, 2001,B&S Directorate, RDSO, Lucknow.

14. Application of Acoustic Emission Technique on Railway Bridges- Study and Analysis of AE Parameters During Static Load Test on Reinforced Concrete Slab (progress report No. 4)-July, 2001, B&S Directorate, RDSO, Lucknow.

15. Application of Acoustic Emission Technique on Railway Bridges- Study of Crack Growth in Steel Bridges (progress report No. 5)-May, 2002, B&S Directorate, RDSO, Lucknow.

16. Application of Acoustic Emission Technique on Railway Bridges- Study of Crack Growth in PSC Bridges (progress report No. 6)-May, 2002, B&S Directorate, RDSO, Lucknow.

17. Acoustic Emission Experience On Bridges By Tyagi R.K. and Srivastava H.M., RDSO, Lucknow paper presented at 13th International Acoustic Emission Symposium 1996, Nara, Japan.

18. Monitoring of Sand Hurst Bridge by Nathawat V., Singh K. and Lal Ramji RDSO Lucknow Paper presented at 5th National Workshop on Acoustic Emission-2002 at Shar, Shri Harikota, India.

19. Acoustic Emission Monitoring for Bridges – Inspection Report by TISEC Inc., Montreal, Quebec.

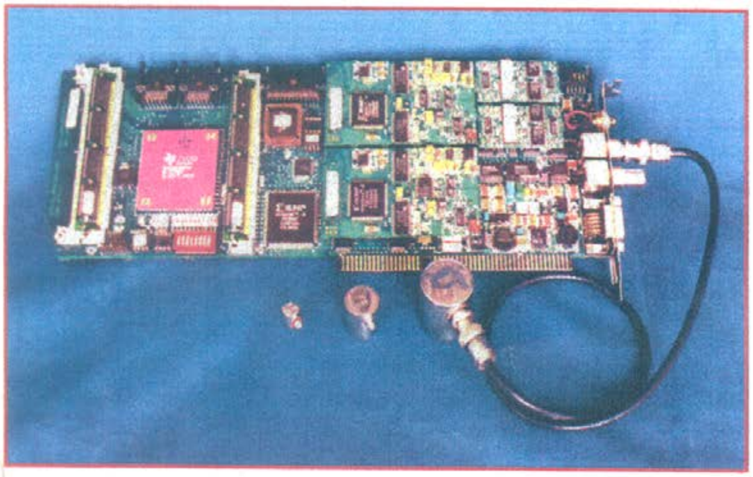
20. Structural Acoustics for Bridge Reliability Evaluation. Inspectiuon Guide by TISEC Inc., Montreal, Quebec.

## 6.0 AVAILABILITY AND PROCUREMENT OF AE EQUIPMENT:

List of Manufacturers of AE equipments and their local agents:

| S.No | Principal | Indian Agent |
|---|---|---|
| 1. | Physical Acoustic Corporation 743,AlexandarRoad, Princeton,N.J.08540, U.S.A. | M/s Motware Private Ltd.<br>9, Sri Narasimharaja Road,<br>PO Box. 6673,<br>Banglore-560002 |
| 2. | Physical Acoustic Corporation Norman Way, over ,Cambridge CB4 5QE U.K. | Physical Acoustic India. Office#: D-293,1st Floor, Sector-17,Vashi Plaza,Vashi, Navi Mumbai-400705 |
| 3. | Sysmon Corporation1207-1207 Gulf Boulevard,Clearwater,Florida, U.S.A.-34630 | |
| 4. | Monac Internation Corporation<br>1313 Border Street ,<br>4 Winni Peg Mnitoba R3H CX4, CANADA | |
| 5. | Hardford SteamBoiler Inspection Technologies 1600 Tribute Road, Sacramento, CA 95815-4400<br>U.S.A | M/S Blue StarLtd;<br>Leo Hpouse<br>88cOld Prabhadevi Road,<br>Mumbai-400 025 |
| 6. | Central Research Institute for Physics of The Hungarian Academy of Sciences,<br>Budapest | Madhuchitt Industries, 64-B, Maker chambers Lii<br>Nariman Point<br>Mumbai- 400 021 |
| 7. | Nf Circuit Design Block Co. Ltd.<br>3-20 Tusnashima Higashi,<br>6- Chome, Kohuku –Ku Yokahama, Japan | M/s CLB Instruments Co.<br>71, 11 Main Road Vyalikaval,<br>Banglore-560 003 |
| 8. | TISEC Inc.<br>2755 Pitfield Boulevard<br>Montrearl QC H4S 1T2,<br>CANADA | SAMRO International<br>174 Siddarth Enclave<br>New Delhi<br>India |

# AEDSP-32/16B & MISTRAS-2001. . . The *True* DIGITAL Generation of Acoustic Emission Testing Systems



### Features:

- 10 MHz sampling per channel
- 16-bit A/D with lower noise (<18 dB threshold)
- Lower power dissipation
- No need for log amp and variable gain preamp
- Increased feature set at >15,000 hits/sec
- Display/storage of both waveform and traditional AE feature data set
- DSP-32 bit (40 MFLOPS) digital power
- Unparalleled 250 MB/sec AE data flow rates
- New user-programmable new features (DSP-ASIC)
- CPU selectable, 15 filters/channel (LP, HP, BP)
- Highest density, quality and reliability in a card (8-layers)

## The AEDSP-32/16B and MISTRAS-2001. . . Advanced Multichannel Digital Waveform Collection Built In

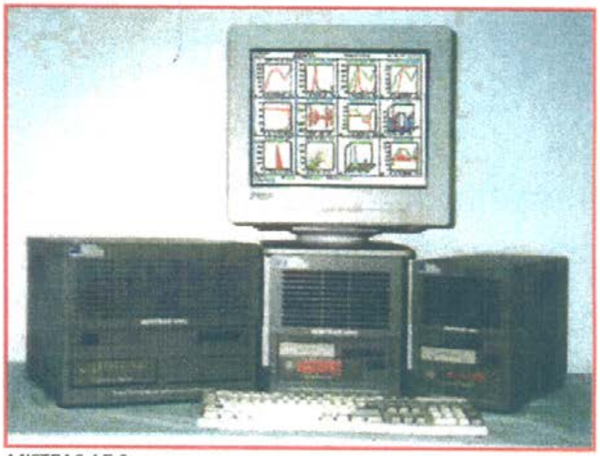
Now, Acoustic Emission (AE) materials testing no longer requires separate instrumentation. Representing the next generation of PC-based data acquisition systems, the AEDSP-32/16B card provides high-speed and high-resolution digital waveform collection built in. Ready to use, this 2-channel AE system offers unlimited potential for signal processing applications and modal analysis. Simply plug the AEDSP-32/16B into your existing computer and you gain all the features of a full-size Acoustic Emission (AE) system along with today's 16-bit Digital Signal Processing power.

### Typical AE Applications for the AEDSP-32/16B and MISTRAS-2001™

- Laboratories
- Advanced Materials
- Stress Corrosion Cracking
- Nuclear Vessels
- Hydrogen Embrittlement
- Tube Trailers
- Aging Aircraft
- Vessels-Ambient, Hot or Cryogenic (Metallic and FRP-Most Applications Done In-Service.)
- R&D Studies
- Bridge Testing
- Pipelines
- Transformers (Partial Discharge)
- Spheres
- Composites
- Rocket Motor

### AEDSP-32/16B for MISTRAS-2001

Massively Instrumented Sensor Technology for Received Acoustic Signals (MISTRAS), PAC's parallel processing AE architecture for (2-256) digital channels.

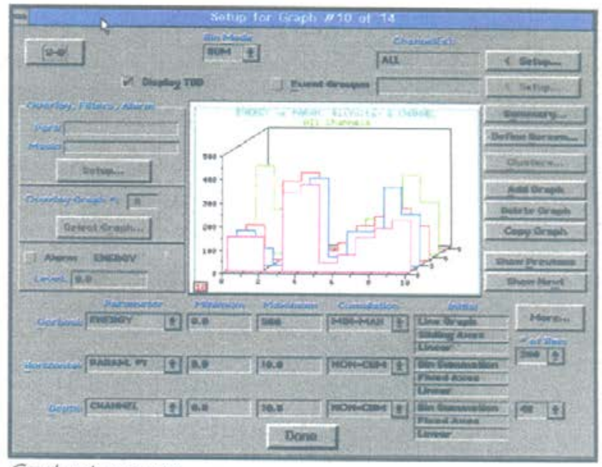


*MISTRAS AE System.*

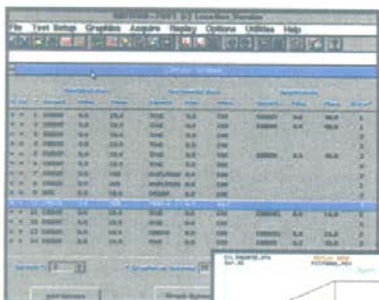

# AEDSP-32/16B/MISTRAS-2001™ User-friendly Software

**Software:**

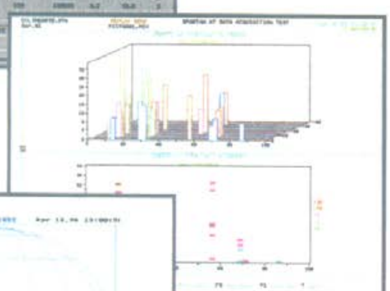
- 32-bit AE software supports multiple PC platforms (Windows, OS-2, DOS)
- Windows-based graphical user interface
- User-defined AE signatures for waveform capture
- Multiple location algorithms, plus arbitrary placement
- Auto-sensor calibration for optimal source location
- Upward compatibility with industry software standards
- PAC-PARS for AI, neural nets, clustering, pattern recognition



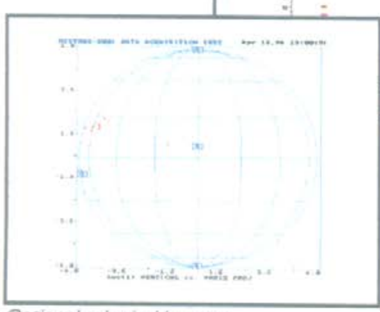

*Graph setup menu.*



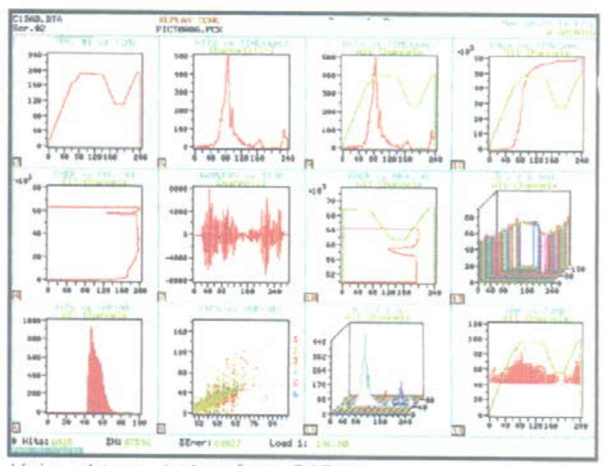
*Graph summary.*



*Three-dimensional graphing.*



*Optional spherical location.*



*Various data graphs from "actual" AE tests.*

*For information on other PAC products and services, visit us on the web at:* www.pacndt.com

The following procedure is to be followed for getting AE signals with the **MISTRAS** system.

**1.** Connect the 1.4 KVA UPS with 230 volts AC main supply to the respective system and then switch the main supply and UPS.

**2.** Selection of sensors & system

a) For concrete structure, MISTRAS system should be used along with R 6I or R 3I sensors. For monitoring larger and smaller areas R3I and R6I sensors respectively are to be used.

b) For steel structure, SPARTAN system along with R15I or R30I sensors is to be used. For monitoring larger and smaller areas R15 I and R30 I sensors respectively are to be used.

**3. MISTRAS SYSTEM**

i) Switch on the MISTRAS system and when C:\> prompt comes follow the instructions as follows.

**C;\> MILOC [ENTER] Type** MILOC **to operate the MISTRAS software and press** ENTER **key.**

**HIT ANY KEY TO PROCEED** message displays and press any key through keyboard.

System displays the **MAIN MENU** of the MISTRAS.

Click **FILE** and then click **READ.INI** option. Select any file from **FILE NAME** option and click OK.

Click **TEST SETUP** choose the title, then select **HARDWARE** option from pull down menu and the system will display the hardware set-up of the selected file. Modify the hardware set-up as per requirement by selecting the options.

Selecting the **CHANNEL SETTING** user can modify the particular option. The option PRE-AMP GAIN (dB) and PRE-TRIG ($\mu$s) options should not be changed and the values 40(dB) and 100($\mu$s) respectively should be kept constant in each set-up.

Click **DATA SETS** option to modify data sets as per the requirement. **PARAMETRIC** option should be selected when any parametric channels are connected to the system. Select the options as per requirement and click **OK**. Click **DONE** to come out of the hardware set-up.

ii) Select **OPTIONS** and **LOCATION** and modify the screen as per requirement by using **TAB** key or $\leftarrow$ key or $\rightarrow$ key from keyboard. Press **F7** to view the sensor locations and distance between them. Changes can be made in sensor locations and distance as per requirement. It is better to keep the distance unit in $\mu$ sec. Press **F1** to return to **LOCATION** set-up. After modifying the **LOCATION** menu press **F10** to come out of the screen.

iii) Select **GRAPHICS** and **DEFINE GRAPH**. Change the values as per requirement and press **DONE**.

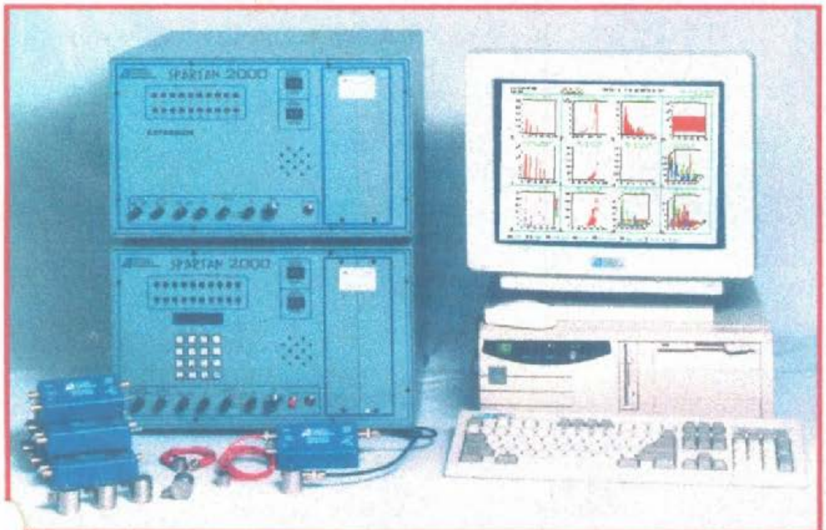
iv) Select **FILE** and **WRITE.INI** to save the existing settings in a file. Type the file name in **FILE NAME** box through the keyboard and click **SAVE**. Now your system is ready for test on a concrete structure.

v) Click **ACQUIRE** and **START**. **TEST STORAGE** screen will be displayed on the monitor and in **FILE NAME** box type the data file name through the keyboard and click **OK**. A screen with selected graphs will be displayed on the monitor and press **ENTER** key from keyboard to start the test. Start the test. After finishing the test press **F10** to stop the test and press **ENTER** key from keyboard.

vi) This will take the user to the main screen. Click **FILE** and click **EXIT** to exit from the system. Click **YES** and system will return to C:\> prompt. Switch off the system now.

ANNXURE-B

# Source Position & Real Time Analysis (SPARTAN 2000™) Advanced AE Instrumentation for Dependable Results




*The SPARTAN 2000™ Acoustic Emission testing instrumentation.*

## The Spartan 2000™ Provides State-of-the-art Data Analysis in AE Testing

To meet today's high demand for reliable, multichannel data analysis which is required in Acoustic Emission (AE) applications, Physical Acoustics Corporation (PAC) presents the ***SPARTAN 2000™ (Source Position and Real Time Analysis).*** For AE applications that call for multiple, independent channels, the SPARTAN system provides high speed **parallel processing** AE feature extraction and real time analysis. Delivering absolutely dependable results, this system performs exceptionally in all test environments.

The ***SPARTAN 2000™*** represents PAC's 4th generation of industry-hardened instruments with a 15-year winning track record, proven in harsh industrial testing environments throughout the world. Capable of handling more than 128 channels of AE, this system embraces the state-of-the-art in multichannel acoustic emission technology by combining this multichannel capability with optional digital transient recorders into one hybrid system. This system is also ideal for knowledge-based and AE code-based systems.

Designed for AE testing environments, such as field testing of vessels or aircraft and where 1, 2 or 14 channels is not nough, the SPARTAN 2000 provides a user-friendly venue o detect and locate structural flaws in a wide variety of materials. Today, the overwhelming majority of field tests are performed with SPARTAN systems.

### Typical AE Applications for the SPARTAN 2000™

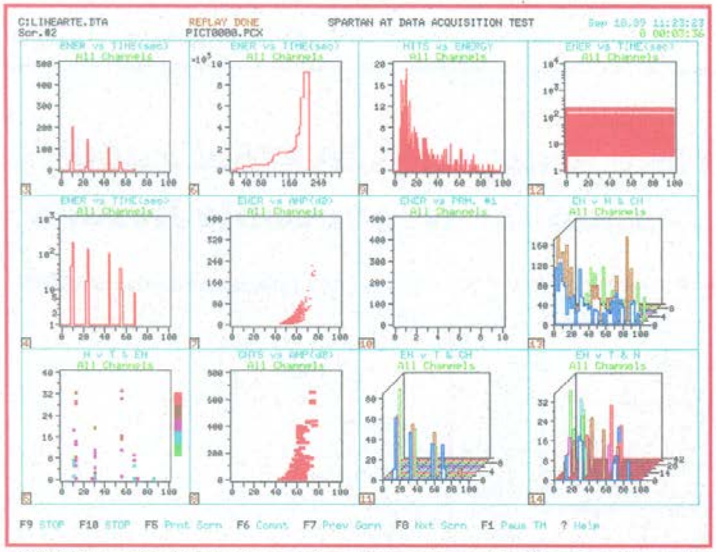
- Advanced Materials
- Bridge Testing
- Stress Corrosion Cracking
- Pipelines
- Transformers (Partial Discharge)
- Nuclear Vessels
- Hydrogen Embrittlement
- Spheres
- Tube Trailers
- Composites
- Aging Aircraft
- Rocket Motor
- Vessels-Ambient, Hot or Cryogenic (Metallic and FRP-Most Applications Done In-Service.)

### Hardware

- Digital AE with optional TRA-212
- Traditional AE Feature Extraction
- >100 Channel Capability
- Built-in Automatic Sensor Testing
- New Parametric Sensor Options
  - ➤ Wind speed, force, pressure, temperature
- Pentium™ 133 MHz or higher SPARTAN 2000 controllers, Notebook interface available (including PCMCIA)
- VGA Video
- Optional Intrinsically Safe (IS) Sensors and Preamps

### Software

- Windows™ Type Software (PAC Version 5.0)
- 32-bit High Speed Software
- 3-Dimensional Graphs
  - ➤ 3-D views can be rotated in 90° increments or display a "top view"
  - ➤ Types include point plots with colored pixels related to value, bar graphs or line graphs
- Color-coded 2-D Graphs
  - ➤ In point plots, colors are used to show activity levels or identify channel numbers
  - ➤ In line plots, up to 6 channels can be plotted on one graph, each in a different, user-defined color
- Acquisition and Replay Graph Screens
  - ➤ Any number of graphs can be displayed from 1 to 12 per screen
  - ➤ 2 texts at the top and bottom of each graph screen provide information status, statistics and help functions



*PAC's "Enhanced Graphing" software further enhances the user friendliness and data analysis capability of SPARTAN 2000™ AE system*

## Software (continued)

- Full Mouse Functionality
- Graphical Filtering
- Parametric Graphing Capability
- Arbitrary Sensor Placement for Location
- Location: Linear, Rectangular, Dual Rectangular
- F-Placement, 3-Dimensional, Triangular, Planar

## Specifications

### Hardware:

**Spartan 2000 Chassis including:**

- **Power:** Linear 350 Watts
- **Interfaces:** Two (2) Serial RS-232C Ports
  One (1) Display Parallel Port
  One (1) Keypad Port
  One (1) IEEE-488 Port
- **Parametric Inputs:** Four Analog +/- 10.0 volt
- **New Parametric Sensor Options:** Wind Speed, Force, Pressure & Temperature
- **Cycle Counter:** One (1)
- **Audio Monitor:** Homodyne or Heterodyne, Alarms Signals: Audio, Visual
- **Activity Lights:** Activity LED for all channels
- **AE Inputs:** 20 BNC AE Inputs
- **Scope/Event Monitor:** Selectable channels on BNC output
- **Bus Expansion:** PAC bus-repeater and output connector for up to 5 optional 20-channel expansion chassis

### AE Performance:

- **Bandwidth:** 3.0 kHz - 1.2 MHz
- **Maximum Output:** 20V p-p into 1k load 16V p-p into 50 ohm load
- **Gain Setting:** 0 - 60 dB in 1dB steps
- **Gain Accuracy:** +/- 1dB
- **Measurement Features:** Counts, Rise Time, Energy, Time of Hit, RMS or ASL, Duration, Amplitude, Hit Definition Time, Hit Lockout Time (HLT), Peak Definition Time, Cycle Counter, 4-parametric; Input (external voltage proportional to external test parameter such as load, temperature, pressure)

### Physical Dimensions:

- **Height:** 10.50 in. (26.7 cm)
- **Width:** 17.50 in. (44.4 cm)
- **Depth:** 23.0 in. (58.4 cm)
- **Weight:** 80 lbs. (36.3 kg)

### Environment:

- **Humidity:** 20% - 90% relative humidity
- **Temperature:** 40° - 95° F (4 -35° C)
- **Power Usage:** 90V - 260 VAC, 48 to 62 Hz

> *SPARTAN 2000™ meets performance criteria of ASTM E 07 for Test Method and Examination of Liquid Filled, Atmospheric and Low Pressure Metal Storage Tanks using AE (in-service & new vessels).*

The following procedure is to be followed for getting AE signals with the **SPARTAN** system.

**1.** Connect the 1.4 KVA UPS with 230 volts AC main supply to the respective system and then switch the main supply and UPS.

**2.** Selection of sensors & system

a) For concrete structure, MISTRAS system should be used along with R 6I or R 3I sensors. For monitoring larger and smaller areas R3I and R6I sensors respectively are to be used.

b) For steel structure, SPARTAN system along with R15I or R30I sensors is to be used. For monitoring larger and smaller areas R15 I and R30 I sensors respectively are to be used.

**3. SPARTAN SYSTEM**

i) Switch on the SPARTAN 2000 system and double click SP2-LOC.BAT icon from desktop.

**HIT ANY KEY TO PROCEED** message displays and press any key through keyboard.

System displays the **MAIN MENU** of the SPARTAN 2000.

Click **FILE** and then click **READ.INI** option. Select any file from **FILE NAME** option and click OK.

Click **TEST SETUP** then select **HARDWARE** option from pull down menu and the system will display the hardware setup of the selected file. Modify the hardware setup as per requirement by selecting the options.

Selecting the **CHANNEL SETTING** user can modify the particular option. The option PRE-AMP GAIN (dB) should not be changed and the value 40 should be kept constant in each setup.

Select the options as per requirement and click **OK**. Click **DONE** to come out of the hardware setup.

ii) Select **OPTIONS** and **LOCATION** and modify the screen as per requirement by using **TAB** key or ← key or → key from keyboard. Press **F7** to view the sensor locations and distance between them. Changes can be made in sensor locations and distance as per requirement. It is better to keep the distance unit in $\mu$ sec. Press **F1** to return to **LOCATION** setup. After modifying the **LOCATION** menu press **F10** to come out of the screen.

iii) Select **GRAPHICS** and **DEFINE GRAPH**. Change the values as per requirement and press **DONE**.

iv) Select **FILE** and **WRITE.INI** to save the existing settings in a file. Type the file name in **FILE NAME** box through the keyboard and click **SAVE**. Now your system is ready for test on a concrete structure.

v) Click **ACQUIRE** and **START**. **TEST STORAGE** screen will be displayed on the monitor and in **FILE NAME** box type the data file name through the keyboard and click **OK**. A screen with selected graphs will be displayed on the monitor and press **ENTER** key from keyboard to start the test. Start the test. After finishing the test press **F10** to stop the test and press **ENTER** key from keyboard.

This will take the user to the main screen. Click **FILE** and click **EXIT** to exit from the system. Click **YES** and system will return to DOS mode. Click X on right hand top corner and thus system will come to WINDOWS.

**ANNEXURE-2**

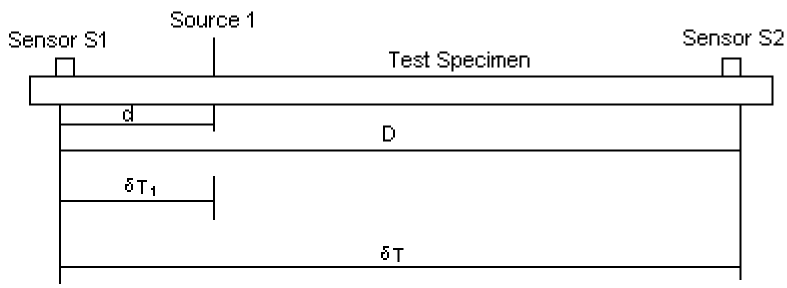
**OPERATIONAL PROCEDURE FOR PERFORMING AE TESTS**

1. Make all the suitable connection as following:-
   - i) Connect the UPS to main power supply with proper earthing.
   - ii) Connect the output of the UPS to AE system.
   - iii) Ensure UPS is connected with single phase 230 V AC supply.
   - iv) Connect Keyboard, mouse & monitor to the main system.
   - v) Turn on the main supply. UPS and the AE equipment subsequently.
2. Actual Test:-
   - A) Sensor Selection
     - i) Steel structure – R – 151 or R – 301
     - ii) Concrete structure – R – 31 or R – 61
     - iii) Steel – if large area has to be monitored then R-151 sensors or if smaller area with more resolution has to be monitored use R-301 sensors.
     - iv) Concrete – if large area has to be monitored then R-31 sensors or if smaller area with greater resolution uses R-61 sensors.
   - B) Sensor Mounting
     - i) Mount the sensors on the test specimen with grease as couplant and magnetic clamp for holding sensors with the surface.
     - ii) Connect the sensors through cables to the instruments.
     - iii) Enter in to the program.
     - iv) Enter in to the data acquisition and confirm that all the sensors are properly connected by doing pencil lead break test.
     - v) Prepare test initialization file with extension INI and acquire data from the specimen and store in data file with extension DTA.
   - C) Data Acquisition, Interpretation & Evaluation
     - i) The conventional parameters used to describe the burst-type emission signal are counts, amplitude, energy, duration and rise-time. Time cycles and external parametric (load etc.) are also included in the hit description. Measures of continuous signals (and also of continuous background noise levels) are RMS & ASL. For data analysis purposes, hit numbers and event numbers and delta T may be included in the data record.
     - ii) Displays can be classified into history plots, location plots and co-relation plots.
     - iii) Data of several trains may be collected in one data file for better interpretation.
     - iv) Interpretation and evaluation are done on-line and the result is available immediately at the end of the test. For post-test analysis following procedure may be adopted.
       - Replaying the data to generate additional display

Filtering the data to eliminate noise or isolate data from a particular source based on time, load location or signal characteristics. With some systems, the filtering process generates a new data file containing only the data of interest. This file may be much shorter than the original data file, so subsequent analysis will take less time. Other filtering techniques include “graphical filtering”. In this technique the first graph is set up such that only the data of interest appears within the plot boundaries. Second and third graph are then setup “filtered” by the first showing any desired presentations of only the data of interest.

## DETECTION OF ACTIVE FLAW LOCATION BY AET

When two sensors are mounted in a structure in linear location, the time difference and the order of arrivals is used to locate the source. Let the source be at a distance d from the sensor S1 and the distance between the two sensors S1 and S2 is 'D' (as shown in fig.). The time difference between the arrivals of the signal at the two sensors is given by




$\delta T = (t1 - t2)$ and the AE wave velocity 'v' is calculated by

$v = D/\delta T$

Then, the source location d from sensor S1 is given by

$d = \delta T_1 \times v$

Where '$\delta T_1$ ' is the time taken by the AE wave reaching sensor S1 from source 1 and 'v' is the velocity of the AE wave.

In two dimensional case, where the source is known to be locate in a plane, the difference in distance travelled by the wave to a pair of transducers can be calculated from the measured time difference. For a given pair of transducers the known time difference value $\delta T$ can be anywhere on the hyperbola. For the same source with another pair of transducers a second $\delta T$ value can be obtained and again trace a hyperbola. At the point of intersection of these hyperbola exists the AE source. This type of location in a plain is termed as planner location. The minimum number of sensors required for two dimensional case in three in triangular and four in rectangular locations.

**Example:**

The actual distance between S1 and S2, D =1000mm

The observed distance between S1 and S2 in terms of time, $\delta T$ = 200 $\mu$s

Therefore the velocity of AE signal v = $D/\delta T$

= 1000/200

= 5 mm/$\mu$s

Active flaw created by Pencil lead break at 250mm, 500mm and 750mm from S1 respectively.

**First Location**

The actual distance between S1 and flaw at 250mm d = 250 mm

| | |
|---|---|
| The observed distance between S1 and flaw at 250mm in terms of time $\delta t$ | = 53 $\mu s$ |
| The calculated velocity of AE signal v | = 5 mm/$\mu s$ |
| Therefore the observed distance | = $\delta t$ X v |
| | = 53 X 5 |
| | = 265 mm |
| Variation | = 265–250 |
| | = 15 mm |
| %age variation | = (15/250) X 100 |
| | = 6% |

**Second Location**

| | |
|---|---|
| The actual distance between S1 and flaw at 500mm d | = 500 mm |
| The observed distance between S1 and flaw at 500mm in terms of time $\delta t$ | = 99.5 $\mu s$ |
| The calculated velocity of AE signal v | = 5 mm/$\mu s$ |
| Therefore the observed distance | = $\delta t$ X v |
| | = 99.5 X 5 |
| | = 497.5 mm |
| Variation | = 500– 497.5 |
| | = 2.5 mm |
| %age variation | = (2.5/500) X 100 |
| | = 0.5% |

**Third Location**

| | |
|---|---|
| The actual distance between S1 and flaw at 750mm d | = 750 mm |
| The observed distance between S1 and flaw at 750mm in terms of time $\delta t$ | = 150 $\mu s$ |
| The calculated velocity of AE signal v | = 5 mm/$\mu s$ |
| Therefore the observed distance | = $\delta t$ X v |
| | = 150 X 5 |
| | = 750 mm |
| Variation | = 750 – 750 |
| | = 0 mm |
| %age variation | = (0/750) X100 |
| | = 0% |

**ANNEXURE-4**

# CASE STUDIES

## Case Study-1

i) **OBJECTIVE** Monitoring of crack in top flange of Sandhurst Bridge (Bridge NO.1/2 UP) of harbor line of Mumbai Division, C.Rly :

ii) **Details of bridge:**

a) **Location** Km. 1/19-2/7 on Sandhurst Road Railway station

b) **Type** Plate Girder Bridge

c) **Length** 39 span of different length. Span No. 18 of 3.315 m length

iii) **Problem** Crack in cover plate of the top chord. The cover plate was cracked throughout its width and the angle plate below this cover plate was also having a crack of about 202 mm parallel to the track. Pits of corrosion are seen on top / bottom chord of the girder at many locations.

iv) **History of bridge** The Bridge was constructed in 1943. Earlier the bridge was having steel troughs with ballast cushion and it was removed during 1978 - 81 and the piers were lifted by about 350 mm. Now the fish plated track is laid with wooden sleepers. The details of the location of the crack are shown in Fig. 1/1.

v) **Instrumentation:**

a) System MISTRAS-2001

b) Sensors R-151

c) Type Linear Location

d) Duration 31-01-2002 to 07-02-2002

e) Loading Sectional local trains

Strain gauges were also fixed near the crack tips and on non crack zone in identical locations to get the strains through AE system.

vi) **Observations:**

a) AE signals recorded for 26 nos. of trains were analyzed for amplitude, counts, duration and energy. The plots of these parameters after AT post analysis carried out by rejecting AE counts smaller than 50 and the plots of these parameters are shown in fig. 3/2. It can be observed from figure-1/2 that crack is active as the data are concentrated at the tips of the crack in all the four parameters.

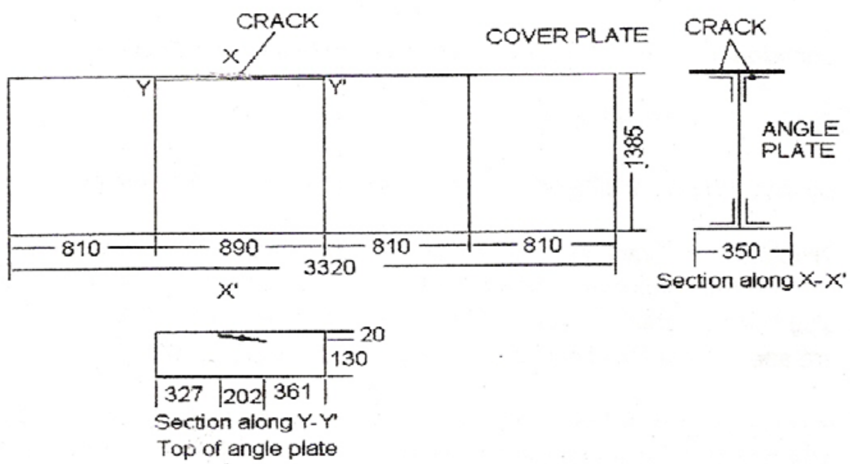
b) Environmental effect: The plot of the acoustic emission parameters recorded to see the effect of environment like wind, weather and effect of traffic on adjacent track shows no AE signals, hence there is no effect of environment on the AE parameters.

c) Effect of stationary train: The effect of dead stop of the train on the effective location shows no AE signal. It indicates that dead load of the train is not sufficient to stimulate the crack.

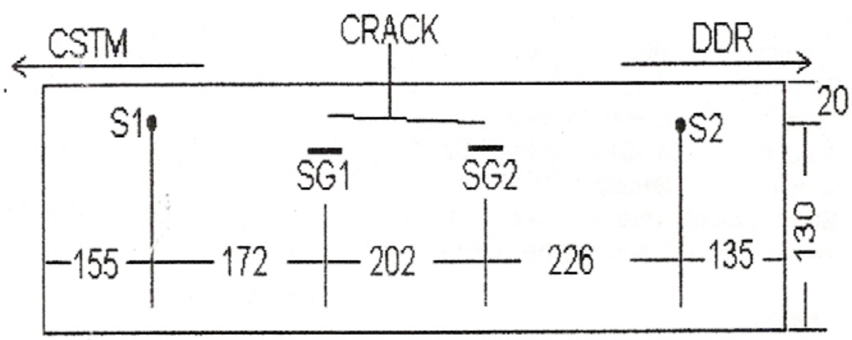
d) Length of Crack: The length of the crack was also confirmed by pencil lead break technique. The lead break was done on both the tips of the crack and near the

e) sensors and length of the crack calculated is 206 mm.

*****




Sectional view of the span




Larger view of section Y-Y'

LOCATION OF CRACK (Span No. 18)

All dimensions are in mm

**Fig. 1/1**

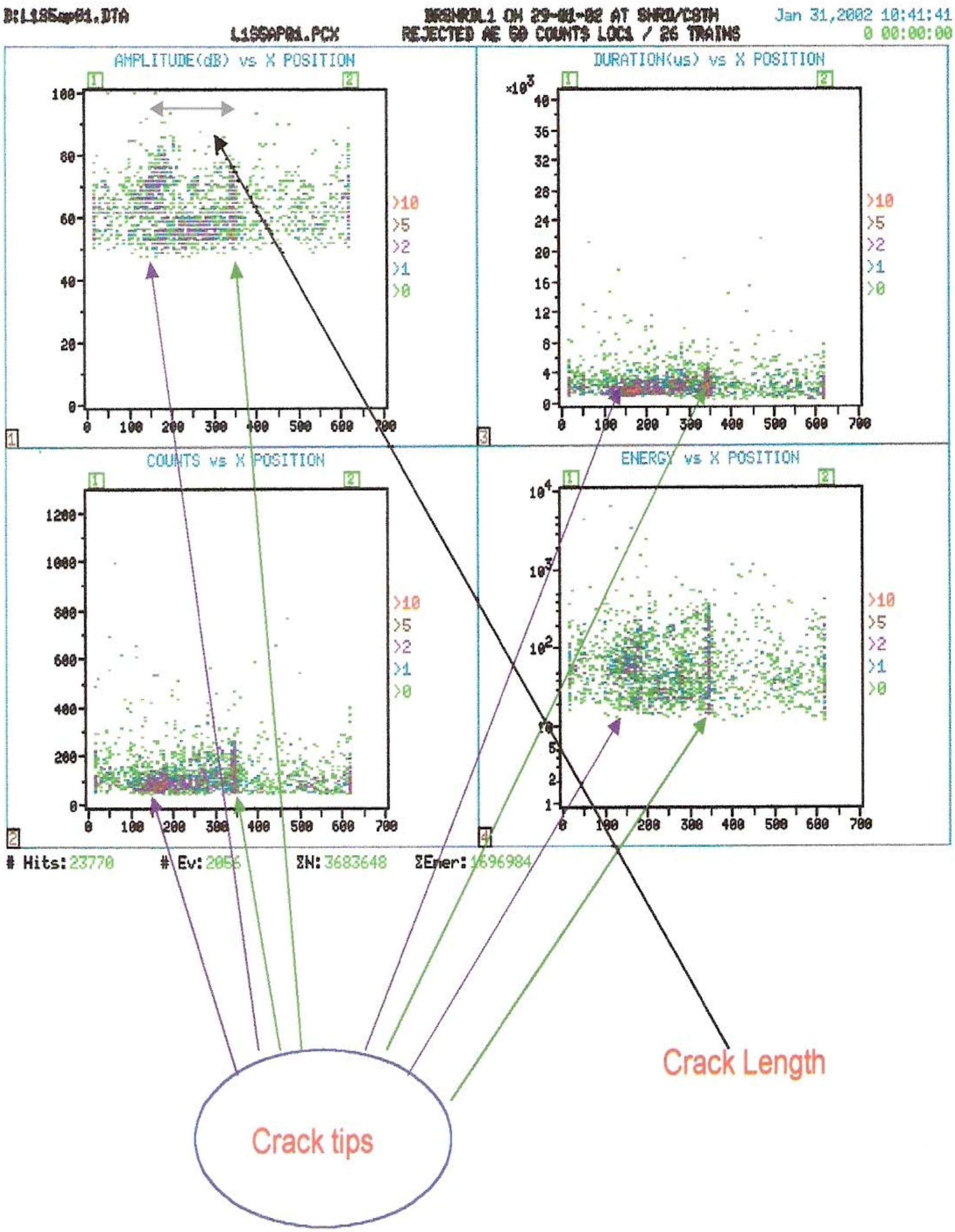

AMPLITUDE(dB) vs X POSITION
DURATION(us) vs X POSITION
COUNTS vs X POSITION
ENERGY vs X POSITION
Jan 31,2002 10:41:41
# Hits: 23770
ΣN: 3683648
Crack tips
Crack Length

**Fig. 1/2**

**Case Study-2**

**i)** **OBJECTIVE:** Monitoring of crack activeness in the diagonal member of bridge no. 65 on Godhara – Anand section of BRC division of Western. Railway.

**ii)** **Details of bridge**

The bridge is located between Km. 52.25 to 53.26 km at Sivalya –Timba Road station of Godhra – Anand section of BRC division of W. Railway.

Type : Open web through girder

Length: Span 17 X 45.7 m

**iii)** **Problem :** Cracks have been noticed in the diagonal member near panel point gusset in span No. 1. Another crack of similar nature was found in span No.17 The cracked members have been spliced by welding and were functioning satisfactory in the field. AE parameters and strains from the cracked members of the bridge and uncraked identical members were observed for identifying presence of activeness of the crack and to decide necessary remedial measures.

**iv)** **History of bridge**: Bridge No. 65 built in the year 1953 of IRS ML BG standard of 1926. The girder of welded construction with riveted connection speed restriction of 45 kmph has been imposed by the Railway.

**v)** **Instrumentation:**

| | |
|---|---|
| System | : MISTRAS 2001 |
| Sensors | : R 15 I and R 30 I |
| Type | : Linear Location |
| Loading | : Normal sectional trains, |

Location instrumented and sample output of AE emission are shown in fig 2/1 and fig 2/2.

**vi)** **Observations:**

(a) Location 1: ( Angle plate of uncracked diagonal)

The concentration of AE data of High amplitude leads to a possibility of a hidden crack at about 304 mm and 373 mm from the top of the bottom gusset plate of the tested diagonal member. The above diagonal member is identical to the cracked diagonal member as in Location 3. It can also be concluded that a hidden active crack is existing between 304 mm and 373mm from the top of the bottom gusset plate of the tested diagonal member.

(b) Location 2 (Angle plate of cracked diagonal )

No possibility of crack is observed

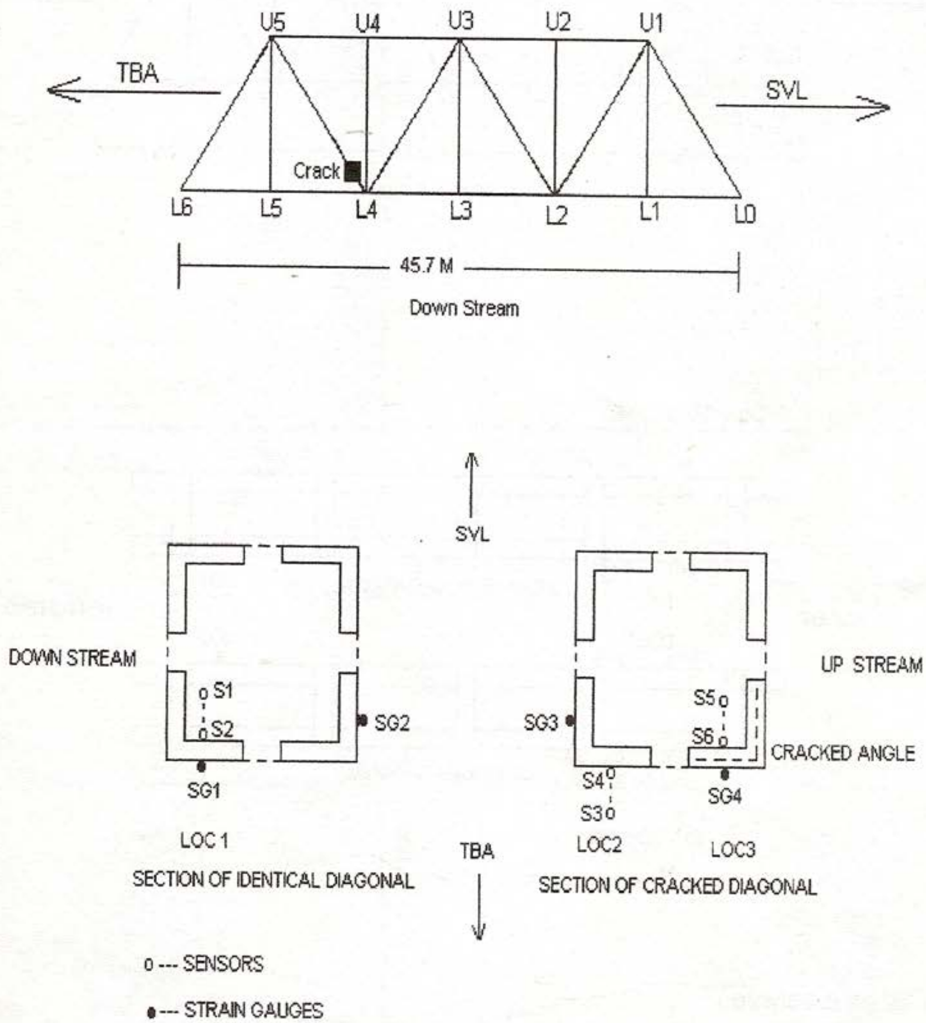
(c) Location 3 (Angle Plate of the cracked diagonal)

The observation leads to the possibility of hidden crack at 243mm from the top of the bottom gusset plate which is just above the repaired angle plate of the diagonal .

As a result, Immediate measure to control the further propagation of crack, like drilling of holes at the extremities of the cracks was recommended and also the use of USFD( Ultra Sonic Flaw Detector ) for metallurgical study was advised.

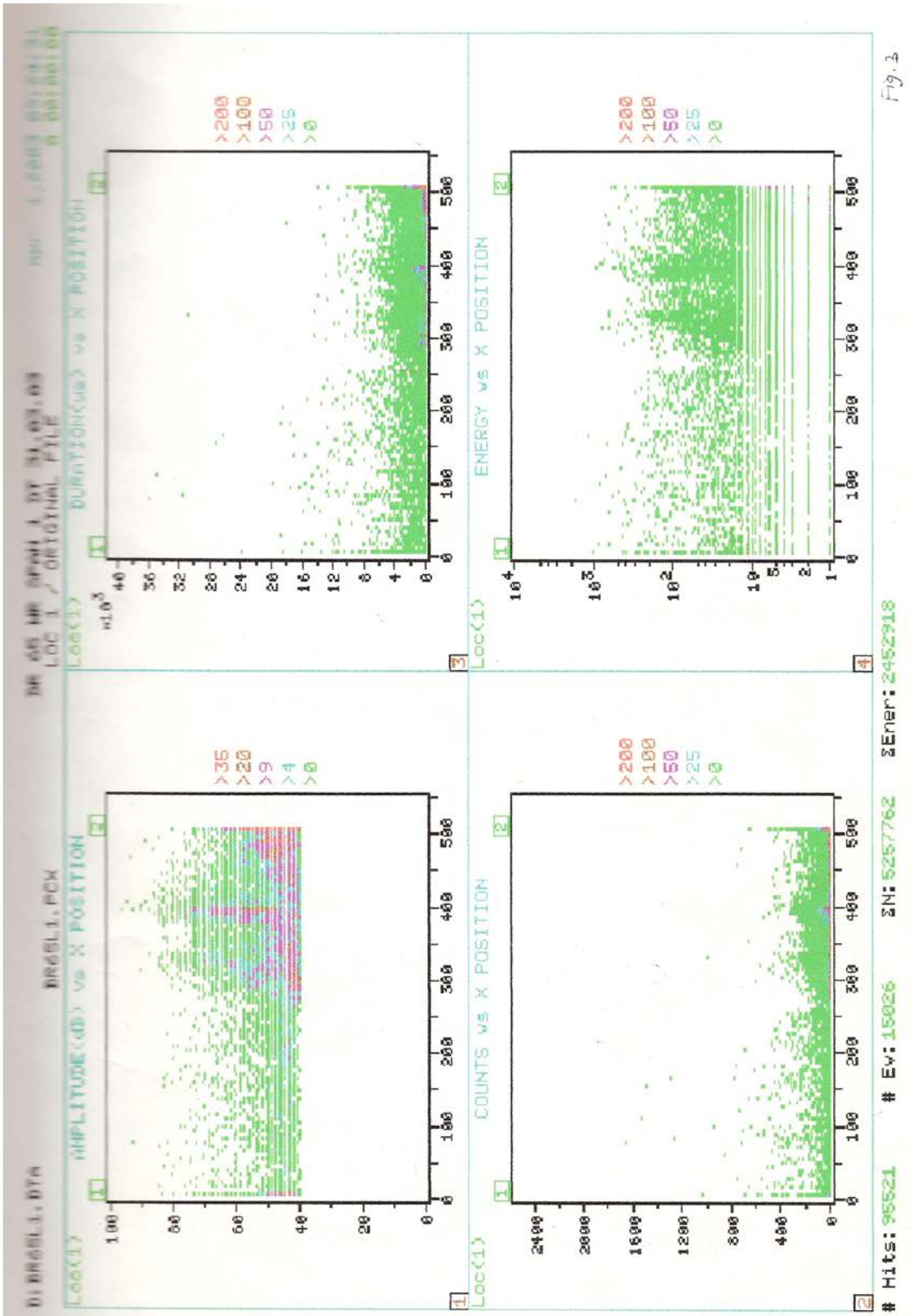
## Location of sensors and strain gauges

Bridge No. 65
Span No. 1




Distance between
S1 & S2 = 500 mm , Gusset Plate & S2 = 200 mm
S3 & S4 = 975 mm , Gusset Plate & S4 = 100 mm
S5 & S6 = 500 mm , Gusset Plate & S6 = 125 mm

Fig. 2/1


AMPLITUDE(dB) vs X POSITION
DURATION(us) vs X POSITION
COUNTS vs X POSITION
ENERGY vs X POSITION
# Hits: 95521
# Ev: 15026
ΣN: 5257762
ΣEner: 2452918
Fig. 3

.

**Fig 2/2**

**Case study 3**

**i)** **OBJECTIVE:** Monitoring of the activeness of the crack at the junction of web and flange of the stringer of Br. No. 78

**ii)** **Details of bridge**

Location : The Bridge is located between Sonpur - Hazipur station of Sonpur division , E. Railway. It lies between Km. 296/6 to 270/5-6 over river Gandak.

Type : Open web through girder.

Length : The bridge consists of 8 span of 76.2 meter having two adjoining plate girder bridge [ ( 77 A of 2 x 18.3 m ) from Hazipur end and 78 A of ( 3 x 18.3 m ) from Sonpur end. ) ]

**iii)** **Problem** The Bridge developed some cracks at the junction of web and flange of some of the stringers.

AE parameters were observed near the riveted joints or crack position and away from the riveted joints so as to identify the activeness of the crack.

Locations **instrumented** and a sample output of AE emission are shown in fig 3/1and fig 3/2 respectively.

IV) **Instrumentation**

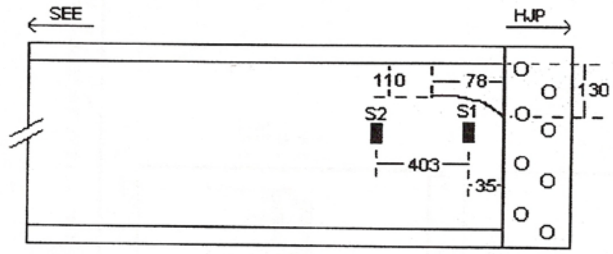
| | |
|---|---|
| System | : MISTRAS 2001 |
| Sensors | : R 15 I and R 30 I |
| Type | : Linear Location |
| Loading | : Normal sectional trains, |

**V)** **Observation**

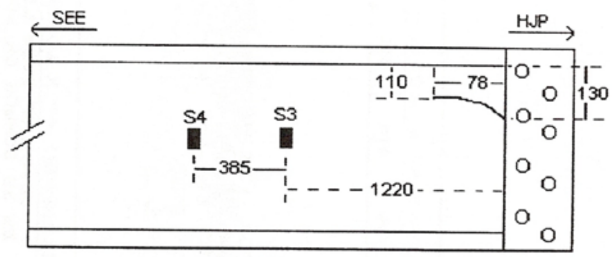
(i) Out of all the tested locations concentration of AE signals of high amplitude can be seen near the crack tip in both location 1 and location 2. So cracks on both the stringer no. 9 and 10 are showing the signs of activeness.

ii) As counts and energy released in location three is sufficiently high than that of location 1. It clearly shows that crack on stringer no. 10 is more active than that of stringer no. 9.

**Location 1 – Stringer No. 9**




**Location 2 – Stringer No. 9**




**Location 3 – Stringer No. 10**

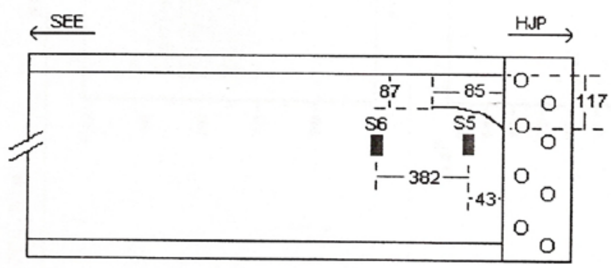



**Fig. 3/1**

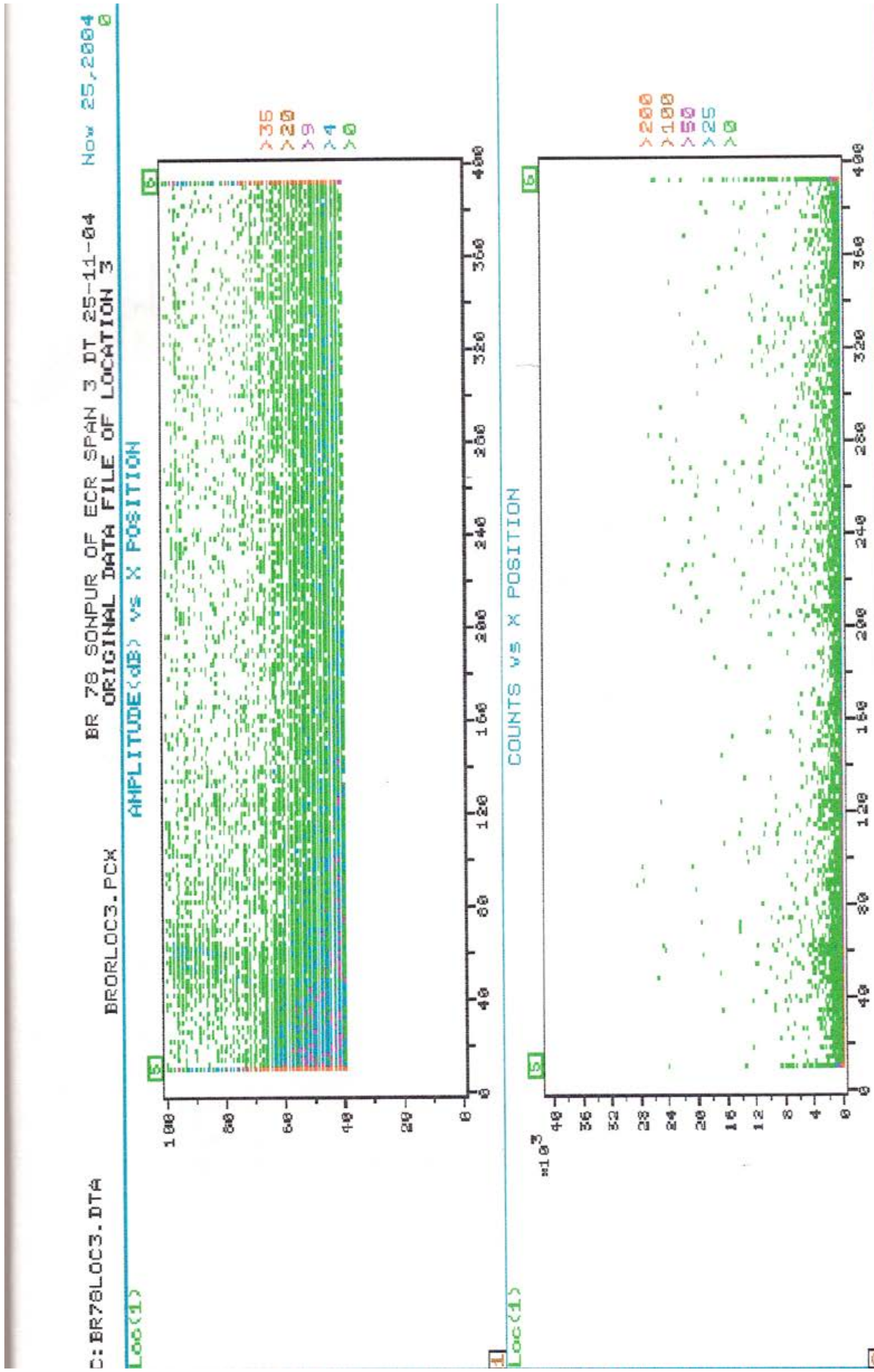

C:BR78LOC3.DTA
BR 78 SONPUR OF ECR SPAN 3 DT 25-11-04
ORIGINAL DATA FILE OF LOCATION 3
Nov 25,2004
BRORLOC3.PCX
AMPLITUDE(dB) vs X POSITION
COUNTS vs X POSITION
# Hits: 377635 # Ev: 20612 ΣN: 1979173300 ΣEngr: 176889581

**Fig 3/2**

**Case study 4**

i) **OBJECTIVE**: For identifying potential failure in critical bridge members AE testing session was conducted in India with the participation of SAMRO, TISEC and Indian Railway work group. This joint effort enabled the testing of ten locations in total for bridge No. 52 and Bridge No. 249. Most of the locations were gusset plates and connections and connection angles, with the exception of two bottom flange angles. The selection of each location was in conjunction with the expectation of Railway.

AE monitoring was conducted to check for crack activity, while both bridges were dynamically loaded with the normal train traffic. Bridge details and observed AE activity are as under.

ii) **Details of bridge**

**(A) Bridge No.52**

Br. No. 52 of Moradabad –Ghaziabad section is 704 meter long over river Ganga. It is constructed of eleven through truss span of single track. All spans were constructed by Head Wright Sons Co. Ltd thron and imported from England near 1900. The bridge will be decommissioning shortly after the construction of a new bridge with 2 tracks. The speed of the trains over this bridge is limited is 45 kmph for all trains.

**(i) Location instrumented**

Eight locations were instrumented and monitored with Acoustic emission on Span no. four of the bridge. The selected areas were: (Ref. fig. 4/1)

1. South west connection angle attaching the web of the south stringer to the web of the 3rd floor beam from the west end of the span.
2. Bottom gusset plate attached to the north girder and the 5th floor beam from the west end of the span.
3. Bottom gusset plate attached to the south girder and the 6th floor beam from the west end of the span.
4. Bottom drain hole in the hanger at the 6th floor beam from the west end of the span.
5. U1 Gusset plate attaching to the south diagonal hanger from the East end of the span.
6. South East connection angle to the L1U1 vertical channel from the west end of the span.
7. West bottom flange angle beneath the south stringer of the floor beam #10 from the west end of the span.
8. East bottom flange angle beneath the south stringer of the floor beam #10 from the west end of the span.

(ii) **Observation:**

All locations on bridge No.52 were monitored for AE and all location was considered inactive.

**(iii) Summary of Test results of Bridge 52 and details of testing done at location 1 is given below:**

**Summary of Test Results Bridge 52**

| Location | Description of Test Location | Acoustic Emission Monitoring Results | Other Inspection Results & Observations | Fatigue Crack Index, D |
|---|---|---|---|---|
| Span #4, 120m TT | | | | |
| 1. | South East connection angle attaching the web of the South stringer to the web of the South stringer to the web of the 3rd floor beam from the West end of the span | Inactive | VT: No crack indication, no corrosion,<br>MT: No crack indication | 1 |
| 2. | Bottom gusset plate attached to the North girder and the 5th floor beam from the West end of the span | Inactive | VT: No crack indication, no corrosion,<br>MT: No crack indication | 1 |
| 3. | Bottom gusset plate attached to the South girder and the 6th floor beam from the West end of the span | Inactive | VT: No crack indication, no corrosion,<br>MT: No crack indication | 1 |
| 4. | Bottom drain hole in the hanger at the 6th floor beam from the West end of the span | Inactive | VT: No indication, surface corrosion,<br>MT: No indication | 1 |
| 5. | U1 gusset plate attaching to the south diagonal hanger from the East end of the span. | Inactive | VT: No indication, surface corrosion,<br>MT: No indication | 1 |
| 6. | South East connection angle to the L1U1 vertical channel from the west end of the span. | Inactive | VT: No indication, surface corrosion,<br>MT: No indication | 1 |
| 7. | West bottom flange angle beneath the sough stringer of the floor beam #10 from the west end of the span. | Inactive | VT: No indication, surface corrosion,<br>MT: No indication | 1 |
| 8. | East bottom flange angle beneath the south stringer of the floor beam #10 from the west end of the span | Inactive | VT: No indication, surface corrosion,<br>MT: No indication | 1 |

### (iv) Inspection Results at Location 1, Bridge 52

**LOCATION DESCRIPTION**

Location 1 (Figure below) was at the South East connection angle attaching the web of the South stringer to the web of the 3rd floor beam from the West end of span # 4. The selection of the component was based on previous visual reports and in consultations with the responsible bridge engineer.

**Figure- Inspection at Location 1**

**PRELIMINARY NDT**

The visual inspection was conducted at the location and around the area of interest. The visual inspection showed the presence of two rivet heads missing from the West face of the connection angle. In both cases, the remaining part of the rivets is inside of the rivet hole. It was observed that a loose bolt and nut was also added in the middle of the connection angle. Furthermore, there was no crack extending from any rivet hole or any metal deformation noted in the proximity of this zone. The surface condition of the connection angles around rivets and along the fillet showed no corrosion.

The magnetic particle testing showed an indication on the North face of the connection angles. Those marking were in between rivet #5 and rivet #6 from the top. However, there was no indication extending from each rivet hole.

## ACOUSTIC EMISSION CLUSTERING

The Acoustic Emission monitoring, as shown in Figure below, revealed significant cluster after properly filtering the events per train passage (filter of time). A secondary filter was added to get proper source location from all 4 transducers (filter location uncertainty filter). Each events were analyzed through wave shape analysis and identified on the loading cycle.

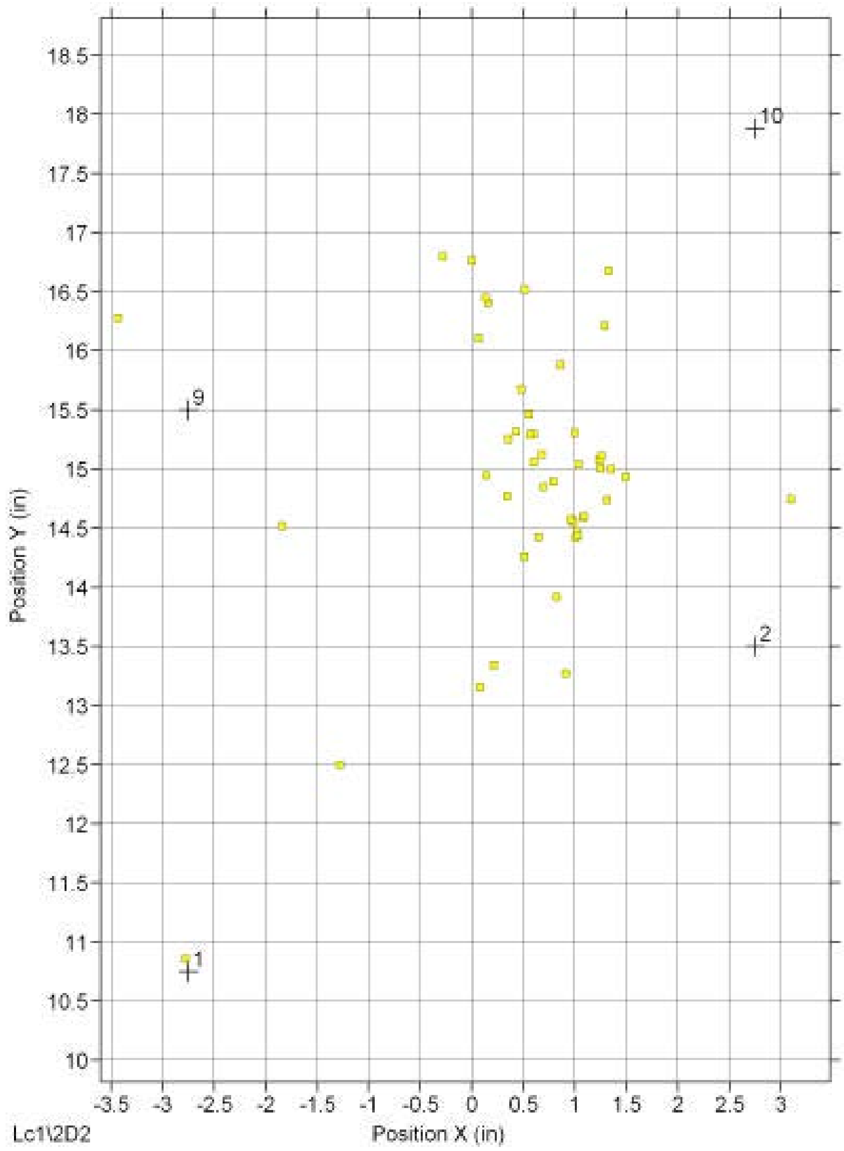



Figure - Cluster analysis at Location 1

## ACOUSTIC EMISSION ACTIVITY/INTENSITY

The analysis of activity and intensity was also performed. As shown in Figure below, the activity and intensity revealed low levels of relative energy and amplitude for each train.

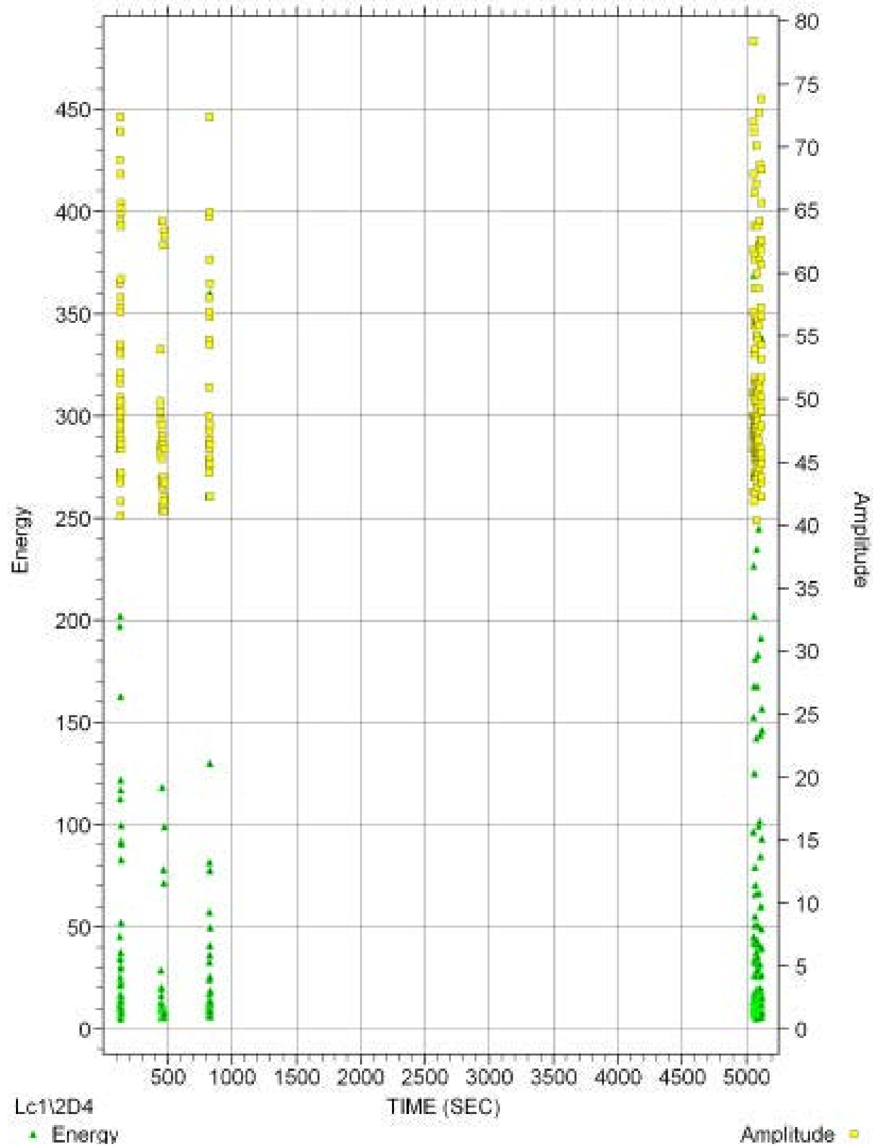



**Figure - Activity and intensity analysis at Location 1**

## ACOUSTIC EMISSION/LOADING CYCLE

The load cycle analysis has confirmed the connection angle to be in the compressive side of the curve during the passage of 7 trains. In Figure below, the maximum recorded compressive loading was of the order of 53 times the static (dead) position of the member.

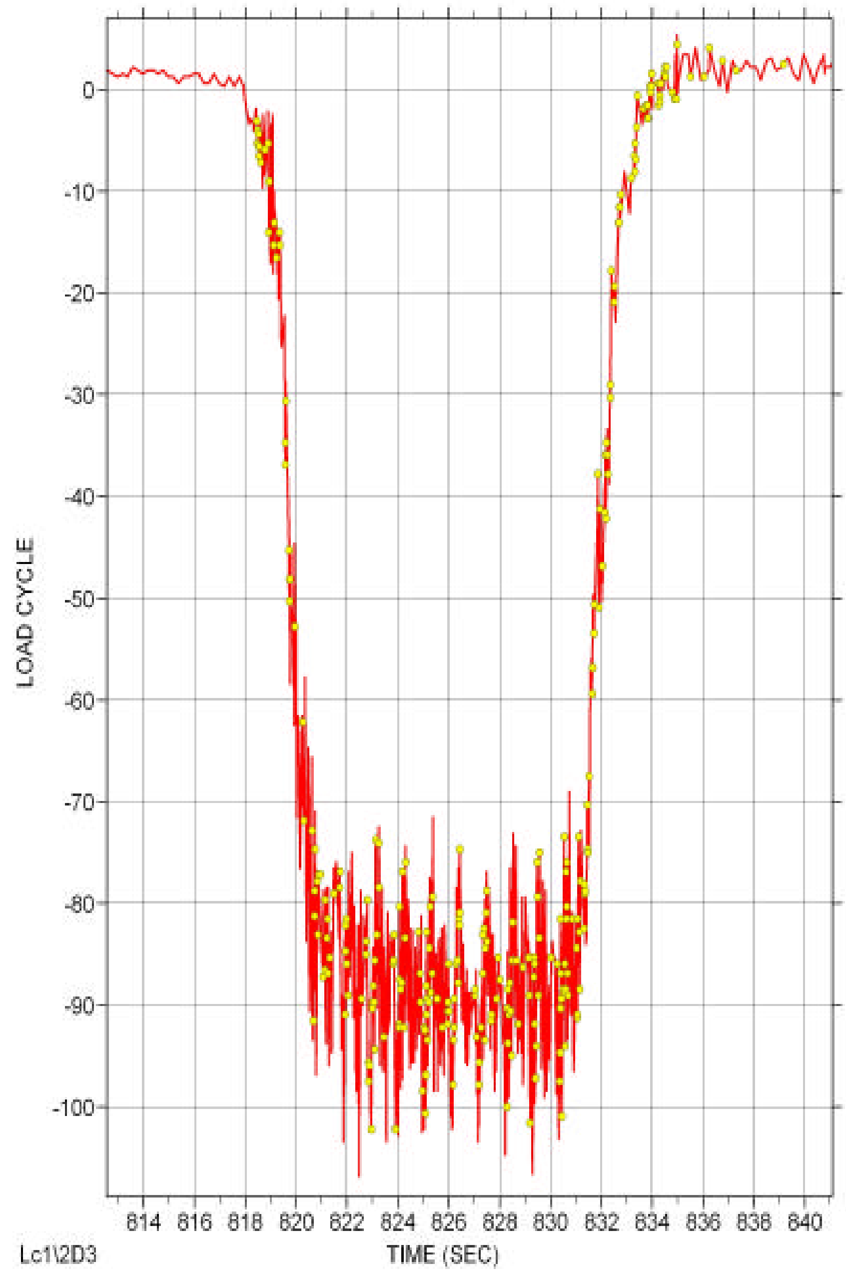



**Figure - Representative Loading cycle at Location 1**

## ASSESSMENT

Based on Acoustic Emission monitoring results and associated load measurement as well as related visual and magnetic particles. It is concluded that location 1 has no acoustic emission related to crack growth; however, the connection angle was subject to active noise emanating from rivet rubbing. The rating from the fatigue crack index is D=1. It would be advisable to repair and replace the missing rivets when time permits.

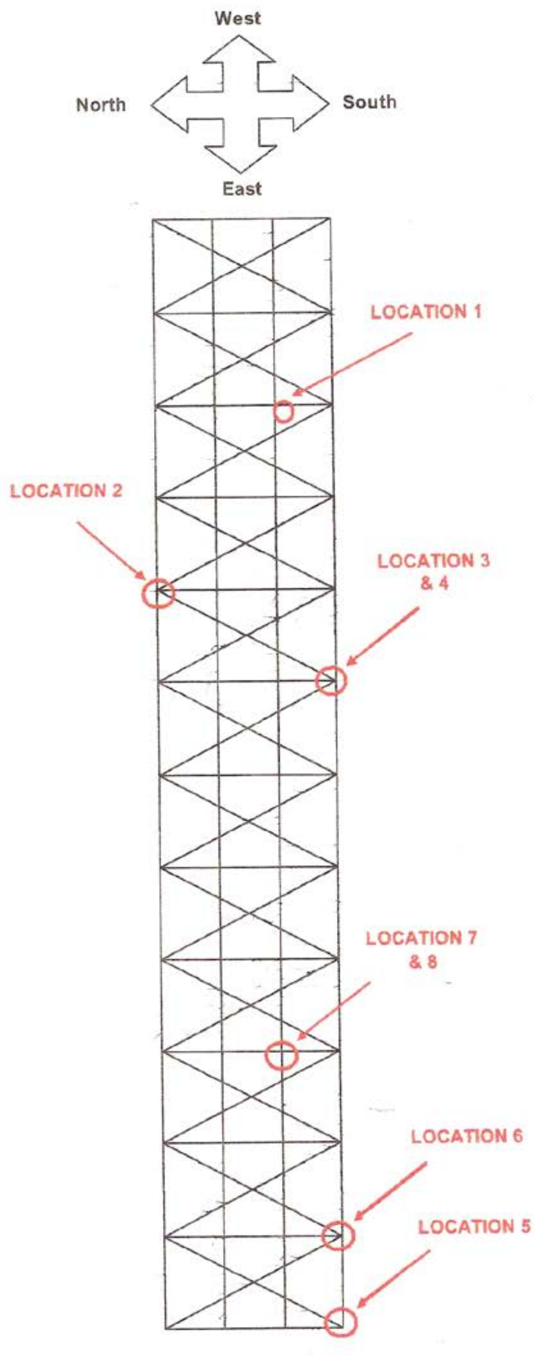



Figure 1. Inspection locations on Span 4 of Bridge 52

**(B) Bridge No.249**

Bridge 249 is located in Delhi-Ghaziabad section of Northern Railway over river Yamuna. The bridge is approximately 732 m long and is constructed of 12 through truss spans of 61m and two spans of 45 m on two train tracks superimposed over two roadways. Speed restriction of 50 Kmph was imposed on this bridge

**(i) Location instrumented**

Two location were instrumented and monitored on span No.3 of bridge 249 using Acoustic Emission. The selected area were as follows (Ref fig 4/2)

1. L2 gusset plate attaching the east vertical hanger U2L2 and the east diagonal hanger U3L2 channel from the south end of the span.
2. L2 gusset plate attaching the west vertical hanger U2L2 and the west diagonal hanger U3L2 channel from the south end of the span.

**(ii) Observation**

Out of all location monitor for AE, Location 1 and Location 2 showed relevant AE activity and was considered active.

**(iii) Summary of Test results of Bridge No. 249 and details of testing done are given below:**

**<u>Summary of Test Results Bridge 249</u>**

| Location | Description of Test Location | Acoustic Emission Monitoring Results | Other Inspection Results & Observations | Fatigue Crack Index, D |
|---|---|---|---|---|
| Span #3, 120m TT | | | | |
| 1 & 2 | L2 gusset plate attaching the East vertical hanger U2L2 and the East diagonal hanger U3L2 channel from the South end of the span. | Active | VT: No crack indication, no corrosion,<br>MT: No crack indication,<br>UT: Indication | 3 |
| 3 & 4 | L2 gusset plate attaching the West vertical hanger U2L2 and the West diagonal hanger U3L2 channel from the South end of the span. | Inactive | VT: No crack indication, no corrosion,<br>MT: No crack indication | 1 |

**(iv) Inspection Results at Location 1 & 2, Bridge 249**

## LOCATION DESCRIPTION

Location 1 & 2 (Figure 30) was at the L2 gusset plate attaching the East vertical hanger U2L2 and the East diagonal hanger U3L2 channel from the South end of the span #3. The selection of the component was based on previous visual reports and in consultation with the responsible bridge engineer.

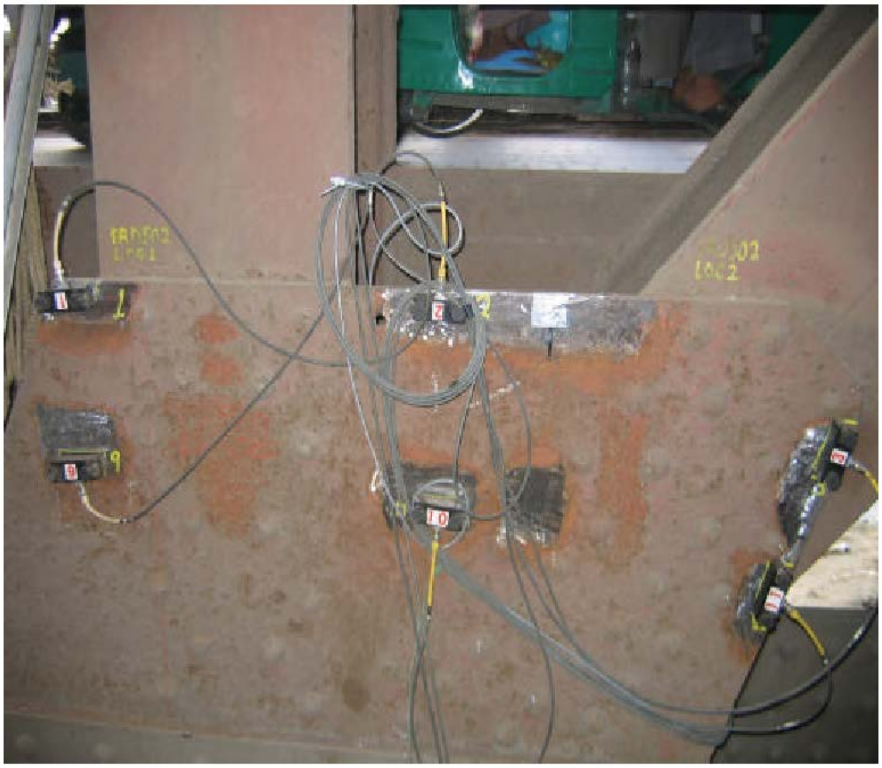


Figure 30. Inspection at Location 1 & 2

**PRELIMINARY NDT**

The visual inspection had showed no crack extension from each rivet hole or any metal deformation in the proximity of this zone. In addition, the surface condition of the gusset plate showed average corrosion.

The magnetic particle testing showed no indication of crack at each rivet hole or any crack on the connection angle.

The ultrasonic inspection showed an indication of a crack extension from the first top rivet hole attaching the diagonal hanger U3L2. Its orientation was assessed to be perpendicular to the direction of the principal stress.

**ACOUSTIC EMISSION CLUSTERI NG**

The Acoustic Emission monitoring revealed significant clustering after filtering the events per train passage (time filter). A secondary filter was added to get proper source location from all 6 transducers (location uncertainty filter). Each hit was analyzed through wave shape analysis and identified on the loading cycle.

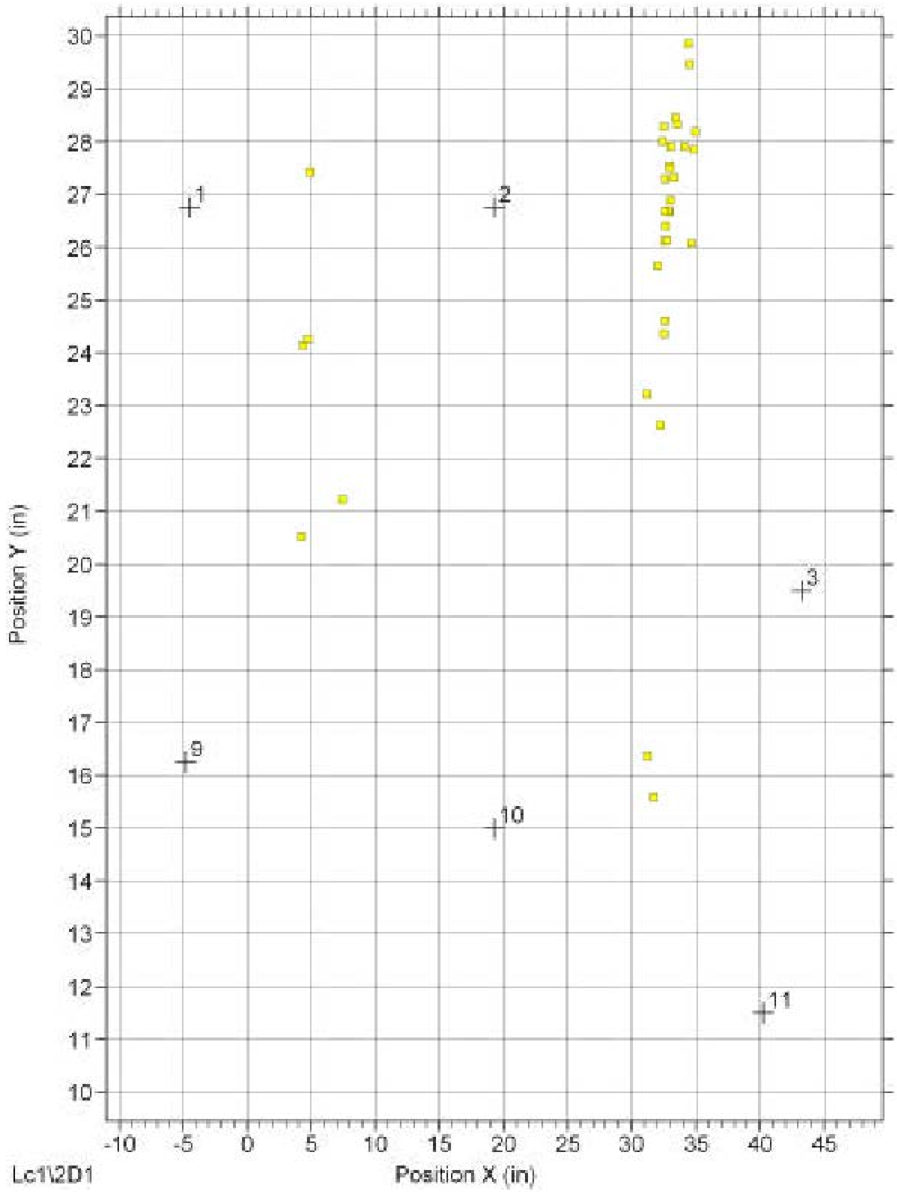



Figure 31. Cluster analysis at Location 1 & 2

(v)

(vi)

**ACCOUSTIC EMISSION/LOADING CYCLE**

The load cycle analysis has confirmed the gusset plate to be in the tensile side of the curve during the passage of trains. In Figure 33, AE was correlated with the maximum recorded tensile loading and it was occurring in the region of the top rivet hole.

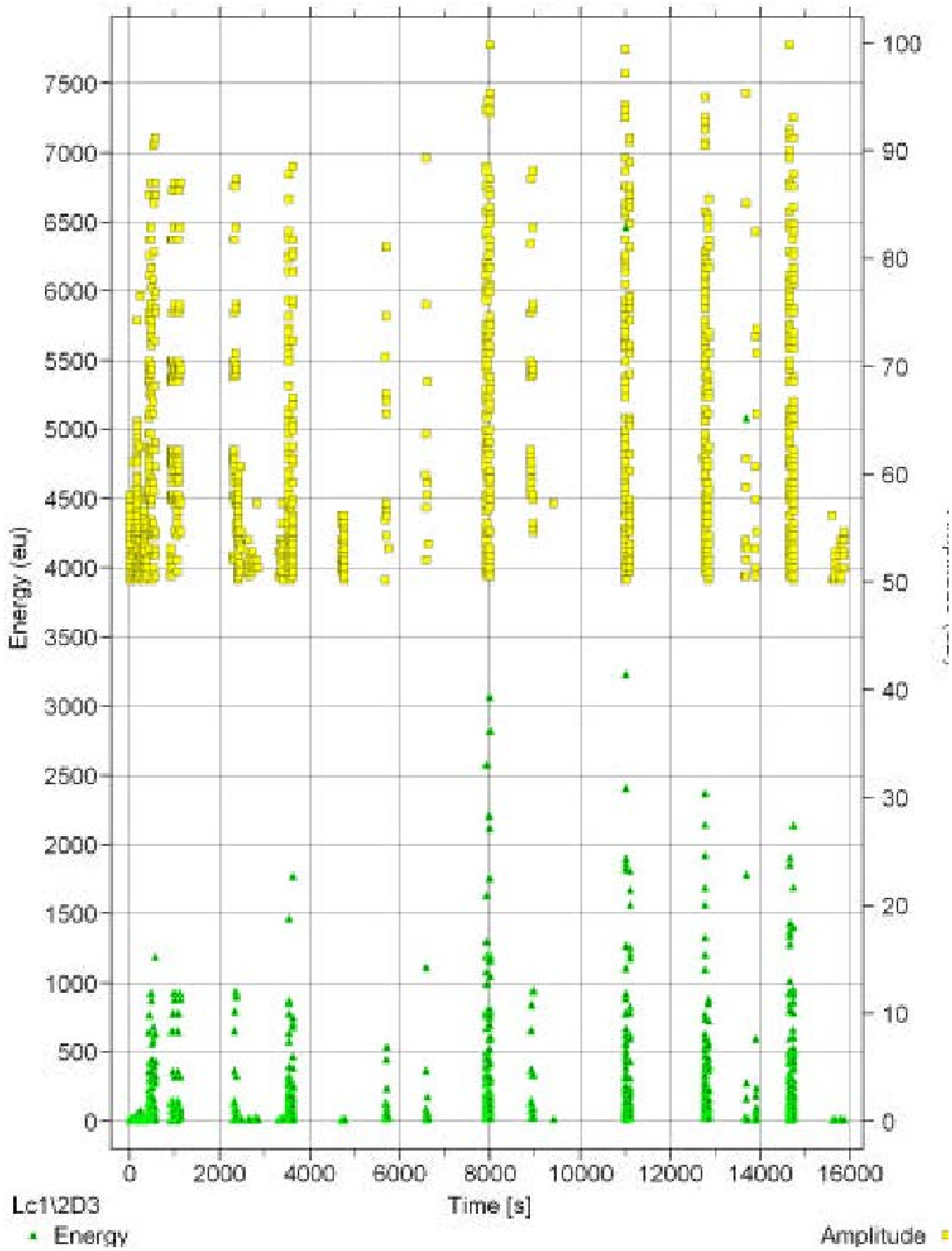



Figure 32. Activity and intensity analysis at Location 1 & 2

### ACCOUSTIC EMISSION/LOADING CYCLE

The load cycle analysis has confirmed the gusset plate to be in the tensile side of the curve during the passage of trains. In Figure 33, AE was correlated with the maximum recorded tensile loading and it was occurring in the region of the top rivet hole.

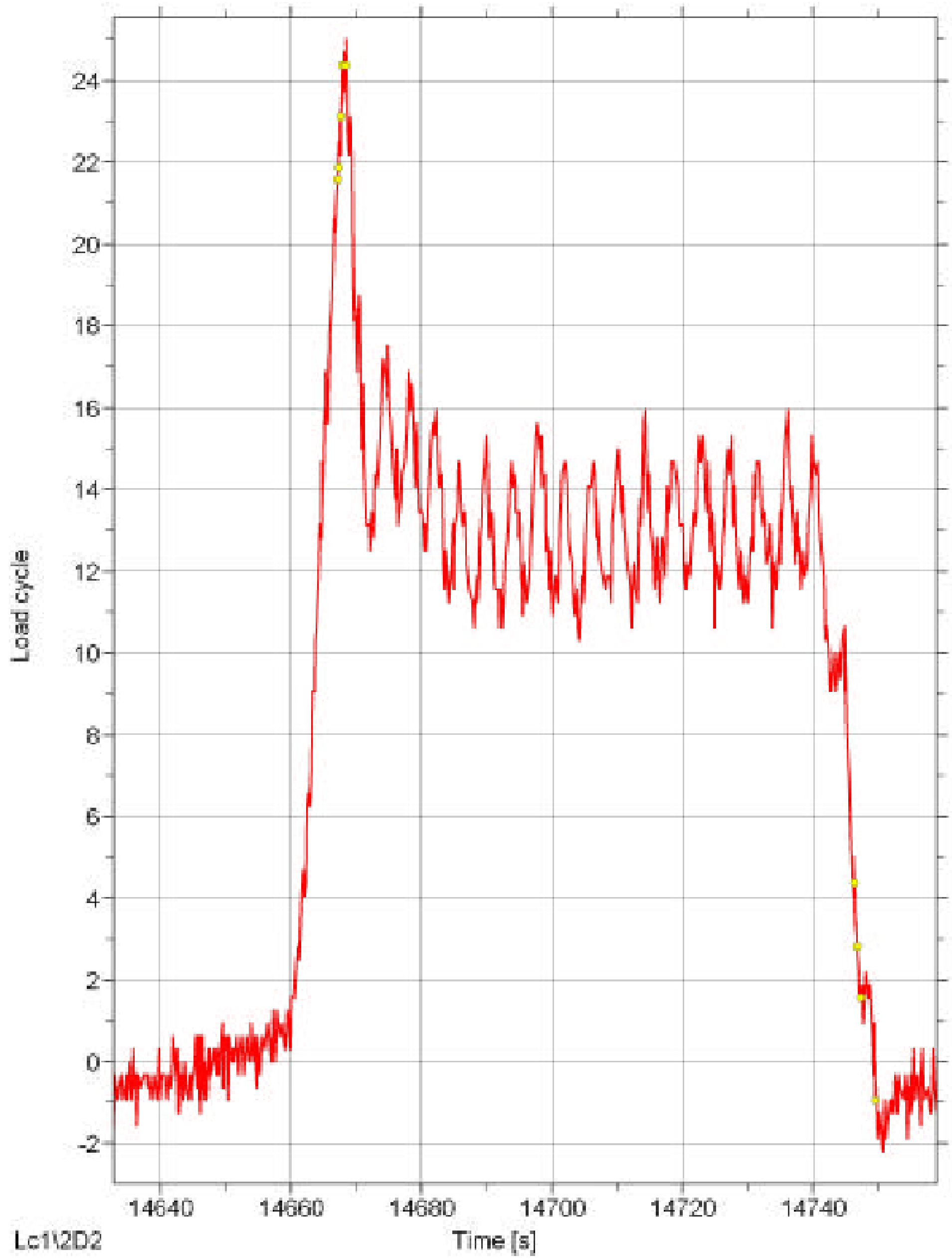



Figure 33. Representative Loading cycle at Location 1 & 2

**ASSESSMENT**

Based on Acoustic Emission monitoring results and associated strain measurement as well as related visual, magnetic particles and ultrasonic testing, it is concluded that Location 1 & 2 have acoustic emission relating to crack growth. The rating from the fatigue crack index is D=3. It is recommended to closely monitor Locations 1 & 2 each year and through engineering critical assessment , establish a critical crack size for the location and the safety factor to be applied to determine a renewal criteria.

### (v) Inspection Results at Location 3 & 4, Bridge 249

#### LOCATION DESCRIPTION

Locations 3 & 4 (Figure below) were at the L2 gusset plate attaching the West vertical hanger U2L2 and the West diagonal hanger U3L2 channel from the South end of the span #3. The selection of the component was based on previous visual reports and in consultation with the responsible bridge engineer.

**Figure - Inspection at Location 3 & 4**

#### PRELIMINARY NDT

Visual inspection showed no crack extension from each rivet hole or any metal deformation in the proximity of this zone. In addition, the surface condition of the gusset plate presents average corrosion. Magnetic particle testing showed no crack indication at each rivet hole or any crack on the connection angle.

#### ACOUSTIC EMISSION CLUSTERING

The Acoustic Emission monitoring revealed no significant clustering after properly filtering the events per train passage (time filter). A secondary filter was added to get proper source location from all 6 transducers (location uncertainty filter). Each event was analyzed through wave shape analysis and identified on the loading cycle.

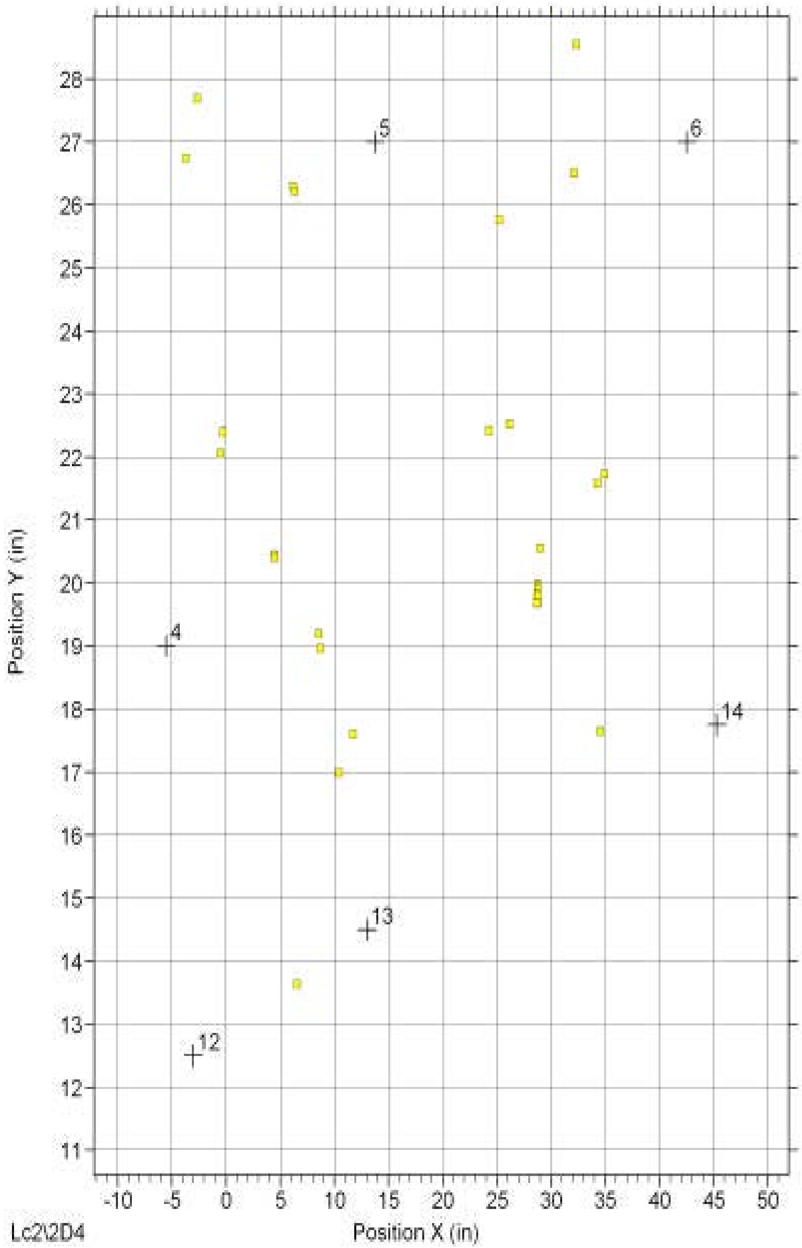



**Figure - Cluster analysis at Location 3 & 4**

## ACCOUSTIC EMISSION ACTIVITY/INTENSITY

Analysis of activity and intensity was also performed. As shown in Figure below, the activity and intensity revealed high levels of relative energy and amplitude for each train.

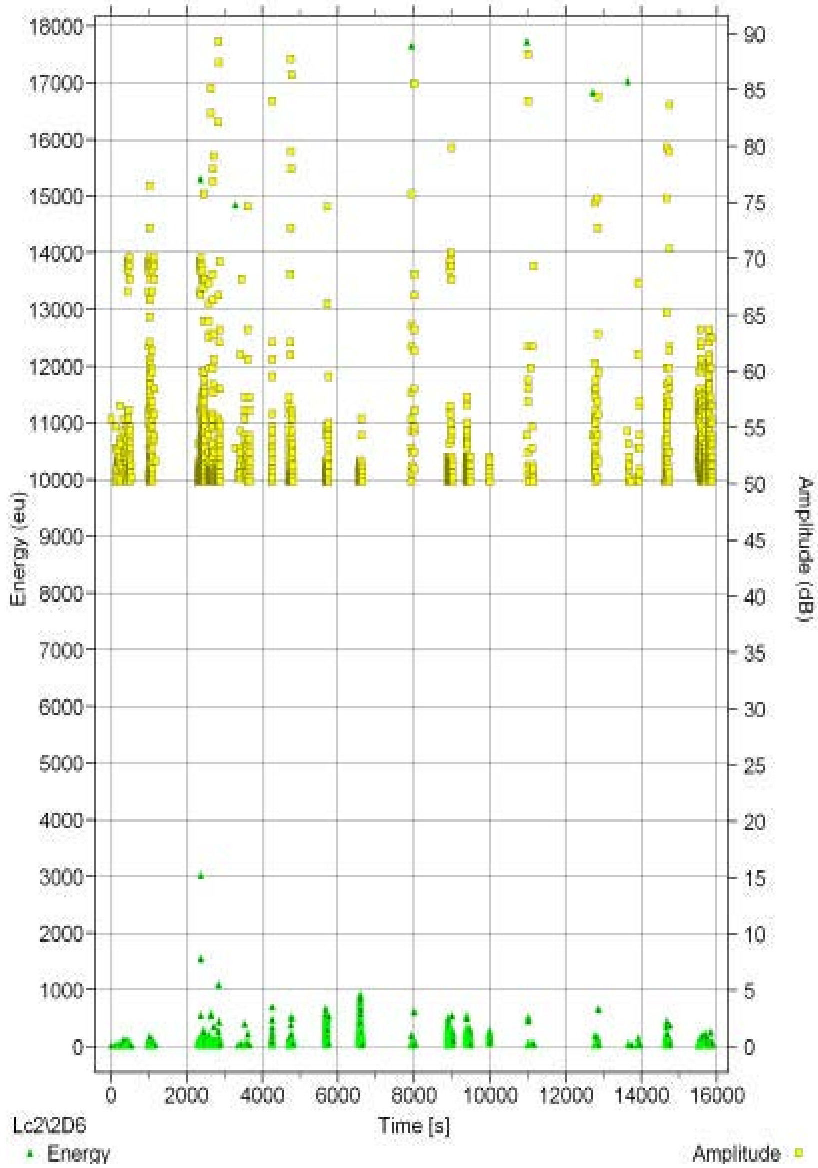



**Figure - Activity and intensity analysis at Location 3 & 4**

## ACCOUSTIC EMISSION/LOADING CYCLE

The load cycle analysis has confirmed the gusset plate to be in the tensile side of the curve during the passage of trains. In Figure below, AE was correlated with the maximum recorded tensile loading and there was no relevant AE activity.

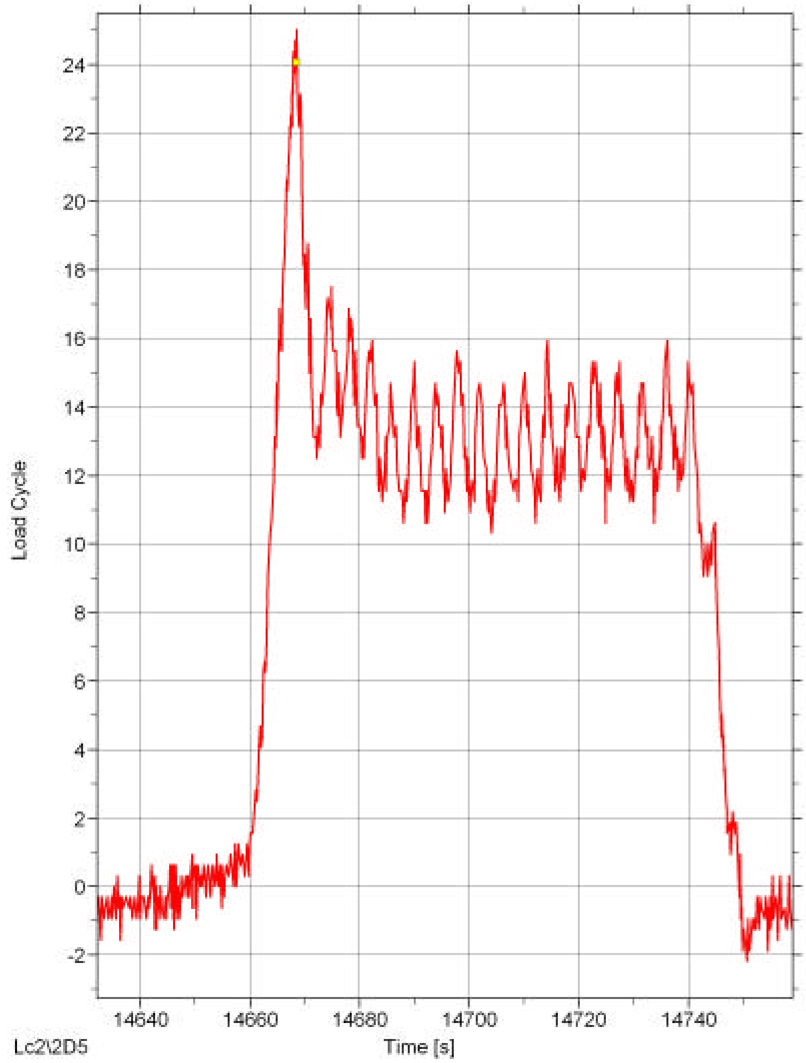



**Figure - Representative Loading cycle at Location 3 & 4**

**ASSESSMENT**

Based on Acoustic Emission monitoring results and associated load measurement as well as related visual and magnetic particles. It is concluded that location 3 & 4 has no acoustic emission relating to crack growth. The rating from the fatigue crack index is D=1. There is no recommendation for location 3 & 4.

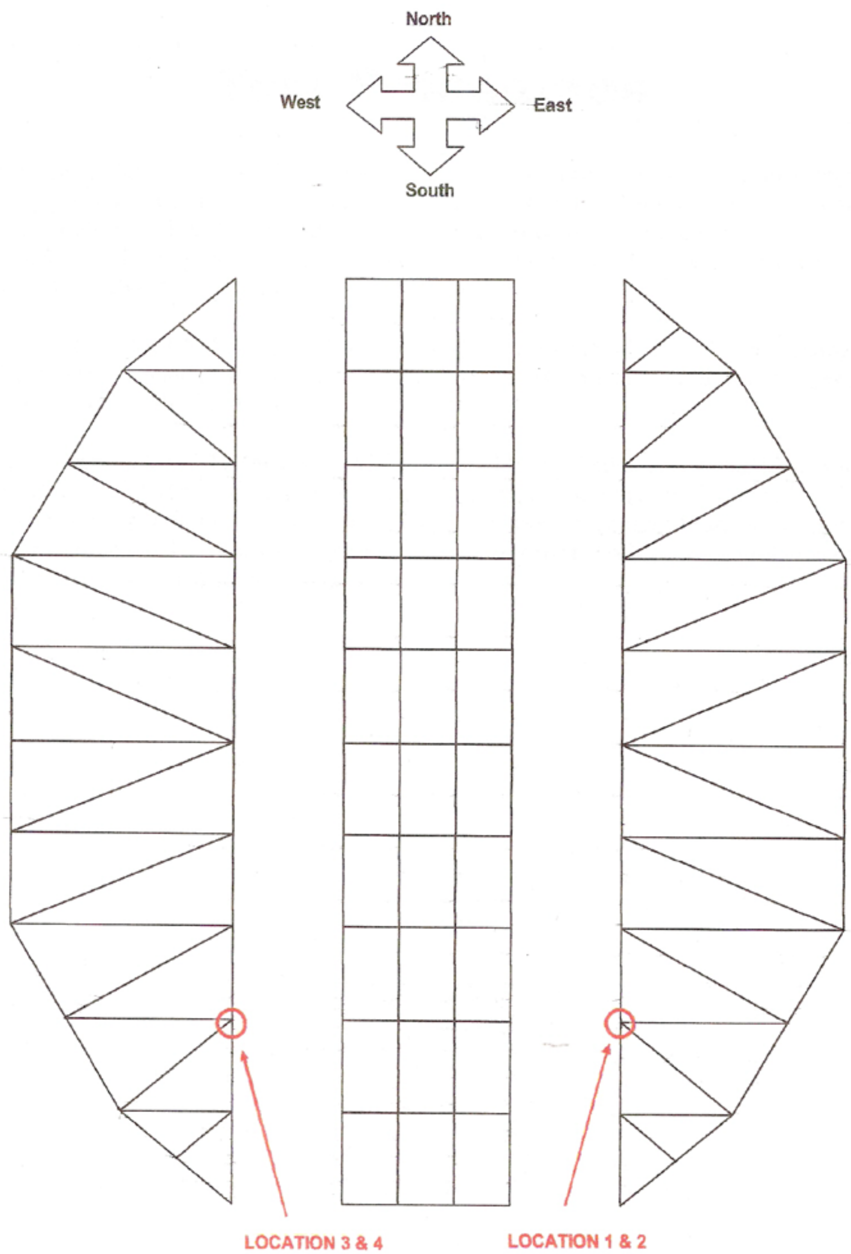



Figure 2. Inspection locations on Span 3 of Bridge 249