ABOLLE-OKOYEAGU, C.J., TORRALBA, J.P., YUHANG, C. and REUBEN, R.L. 2023. Impact source identification on pipes using acoustic emission energy. *e-Journal of nondestructive testing* [online], 28(1): 56 papers from the 35th European conference on Acoustic emission testing 2022 (EWGAE35) and the 10th International conference on acoustic emission testing 2022 (ICAE10) (EWGAE 2022), 13-16 September 2022, Ljubljana, Slovenia, pages 1-12. Available from: https://doi.org/10.58286/27611

Impact source identification on pipes using acoustic emission energy.

ABOLLE-OKOYEAGU, C.J., TORRALBA, J.P., YUHANG, C. and REUBEN, R.L.

2023

35th European and 10th International Conference on AE Testing
13th-16th September 2022 - Ljubljana, Slovenia

IMPACT SOURCE IDENTIFICATION ON PIPES USING ACOUSTIC EMISSION ENERGY

Chika Judith Abolle-Okoyeagu[1], Javier Palacio Torralba[2], Yuhang Chen[2] and Robert Reuben[2]

[1]Robert Gordon University, Aberdeen, UK; j.abolle-okoyeagu@rgu.ac.uk
[2]Heriot Watt University Edinburgh, UK; jp27@hw.ac.uk, r.reuben@hw.ac.uk
*Correspondence: j.abolle-okoyeagu@rgu.ac.uk

ABSTRACT

Impact is a common source of damage in pipes and pipeline systems and detecting the location and nature of damage is vital for reliability and safety of these systems. The main difficulty in the use of AE technology for such applications is being able to investigate the extent to which the temporal structure of such a non-impulsive event can be reconstructed using sensors located on the external surface of a pipe at some distance from the source. There is currently no reliable way of relating the temporal structure of the generating event to the temporal structure of an AE source. This work uses a set of matching AE experiments and finite element simulations to study the relationship between the generating AE event (dropped ball on a steel surface) and the resulting stress-time history recorded at a given point on the surface of the pipe.
Two test objects were used; a solid cylindrical steel block of diameter 307mm and length 166mm and a 2m pipe length of diameter 100mm and wall thickness 10mm. The AE resulting from the surface impacts was recorded over a period of 2 seconds for both experiments and simulations. The work builds on an earlier study with the same test objects using impulsive sources.
The results confirmed that a mechanical disturbance which is extended in time can be identified from its energy-time imprint carried on the stress wave.

Keywords*:* Acoustic emission, finite element analysis, AE energy, solid cylinder, steel pipe.

1. Introduction

Pipelines play a significant role in the transport of both gases and liquids, particularly in the oil and gas industry. There is a constant interest in improved levels of monitoring of these structures, as pipeline accidents are quite often disastrous both to people and the environment [1]. A good number of studies have recommended Acoustic Emission Monitoring (AEM) for the continuous surveillance of structures, machines and processes [2-5] and this paper tackles how a quantitative approach can be applied to pipeline integrity assessment.
AE is a term used to describe high-frequency (0.1 to 1MHz) elastic stress waves generated by the rapid release of mechanical energy often associated with structural degradation [6,7]. In pipelines, the main known sources are leaks, fatigue, and impact from external forces, although, in some applications, flow noise and abrasion may generate significant AE. Over the years, AET has become an accepted Non-Destructive Testing (NDT) technique with potential applications to pipelines [8] and this is due to its ability to provide information on the structural health of a pipeline

 https://doi.org/10.58286/27611

by using relatively few monitoring points and relying on propagation characteristics to locate faults such as leaks.
Just as in any other NDT testing technique, AET has limitations, the most significant being its inability to effectively determine as many characteristics of an AE source as one might expect for its very high temporal resolution. Much of this is because a number of processes produce AE, and not all of these give rise to signal that is of interest. There are, therefore, still research challenges in determining the nature, severity and location of multiple and/or prolonged sources, using signals acquired at one or more sensors mounted on the pipe surface [9].
Although the use of Finite element analysis (FEA) to simulate acoustic emission wave propagation has been a subject of research for over two decades [10-12], much of the work applying FEA has been focussed on a description of propagation [13,14].

2. Overall approach

This approach follows from an earlier study with the same test objects using impulsive sources [15]. Two different test objects were used; a solid cylinder and a 2m steel (ASTM A106/99) pipe. The solid cylinder was 307mm diameter and 166mm long and was used standing on one of the circular faces, with the opposite circular face being used as the test surface (Fig. 1).
The pipe was of length 2m, external diameter 0.08 m and internal diameter 0.1m. The external cylindrical surface was used as the test surface with both source and sensors being mounted on it (Fig. 2). A guide tube was used to guide the ball bearing on to the centre of the surface of the cylinder. The configuration was chosen to be close to the actual technological application.
For the experiments on both the pipe and the solid cylinder, a ball bearing drop was used to simulate sources with an extended temporal structure. The preamplifiers were set at a gain of 40dB and a sampling rate of 5Msamples/s with a pre-trigger of 1000 points was used. The system also acquired 50,000 points from the second sensor interlaced with the trigger. Three different sized balls (17g, 3g and 0.3g) were dropped from the same height (0.3m) onto the surface of both the solid cylinder and the pipe. Unlike the ball bearing drop on the solid cylinder, the ball bearings were dropped onto a flat steel plate placed on the pipe, for practical reasons.
Abaqus 6.10 was used for the simulations to model a steel cylinder and pipe fixed at both ends and subject to loading 0.2m from one end. The cylinder, pipe and ball models were both simulated as three dimensional, elastically deformable steel solids. Both the steel ball and pipe sections were modelled as 3D homogenous linear elastic continua, and an 8-node linear brick elements (C3D8) were used to discretize the model. Linear elements being used on the assumption that the stresses/displacements caused by the deformation and the propagating wave were within the elastic range. An element of size 0.01mm and time step of 1×10^{-9} second were used for the simulations. Stress time-histories were recorded at a distance of 0.5m from the location of impact for a total time of 2s.
Just as with the experiments three different sized balls (17g, 3g and 0.3g) were simulated to drop from the same height (0.3m) onto the surface of both the solid cylinder and the pipe.
The analysis was carried out at two different timescales; short (initial interactions free of reflections) and long (involving several bounces).

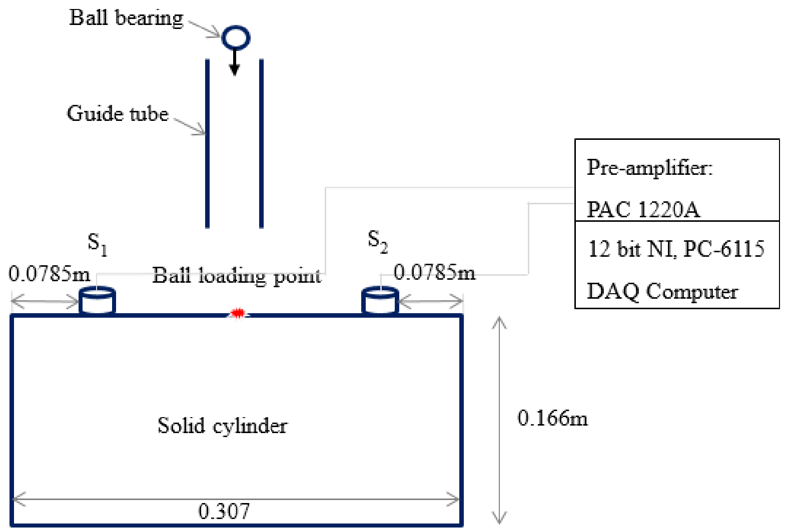


Fig. 1: Schematic representation of ball bearing drop on solid cylinder.

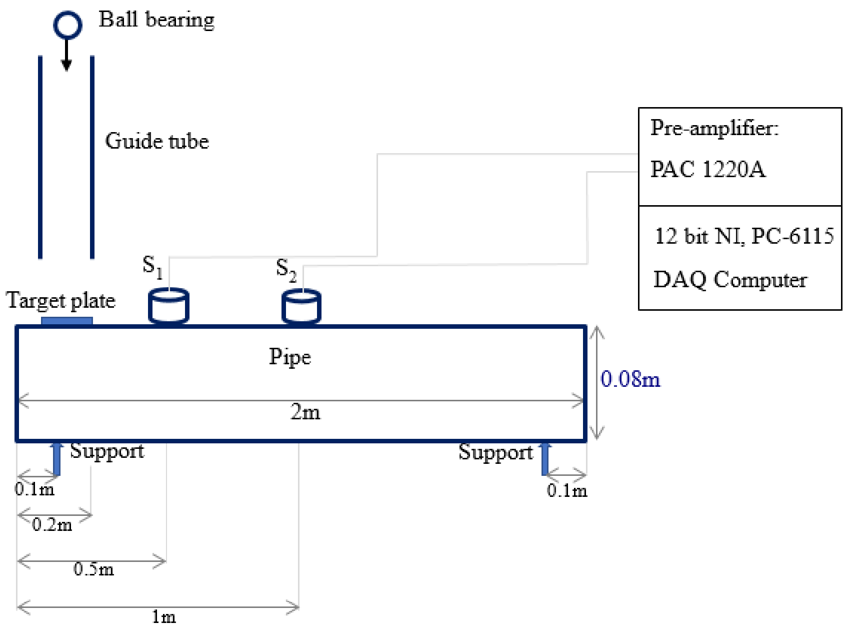


Fig. 2: Schematic representation of ball bearing drop on pipe.

3. Experimental result and analysis

3.1 Solid cylinder

Fig. 3 shows typical raw AE signals for the three potential energies and ball sizes. As can be seen, the ball bounces several times over a period of around 1second, each bounce being characterised by a burst of AE lasting about 0.1second with an increase in energy as the ball mass is increased.

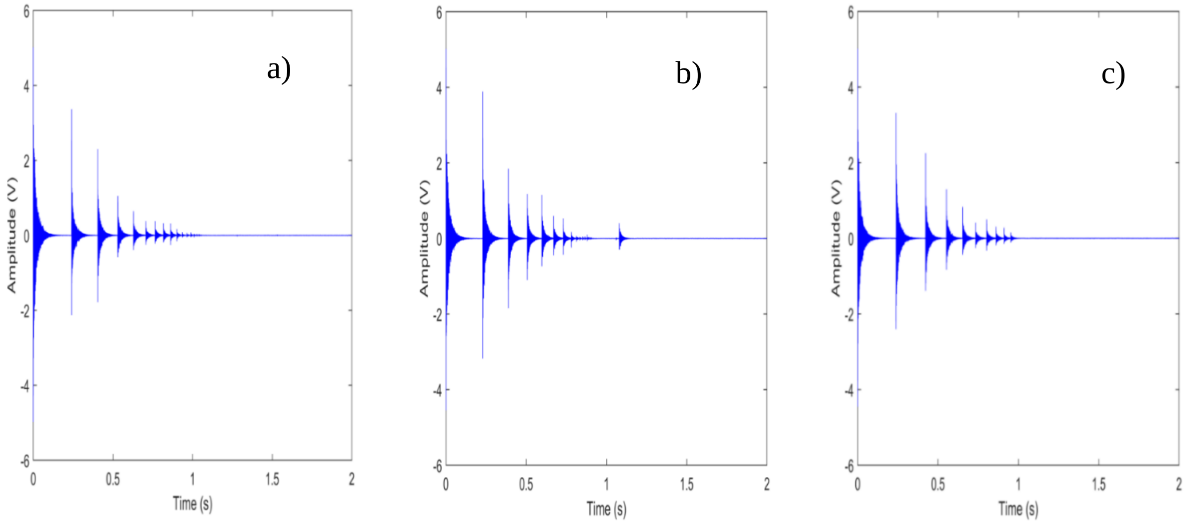


Fig. 3: Typical long-timescale AE signal balls dropped from 30cm height. a)17g b) 3g c) 0.3g on the solid cylinder.

Fig. 4 shows 140μs around first wave arrival for the three ball sizes. It can be seen that, irrespective of the ball bearing size, each first arrival is characterized by a low amplitude component of duration about 1μs, followed by a high amplitude component, which contains the peak amplitude.

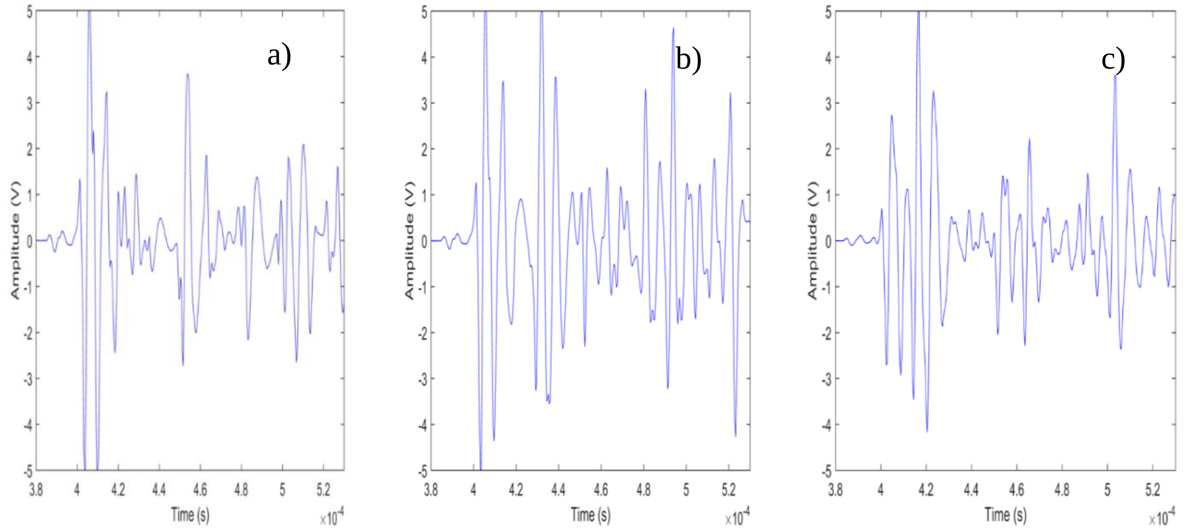


Fig. 4: Short-timescale AE signal dropped from 0.3m unto the solid cylinder. a)17g b) 3g c) 0.3g.

The measured (AE) energy was then calculated for each of the first four impacts for each of the ball bearing masses by integrating over the entire length of the burst.
Fig. 5 shows a plot of the measured energy against the incident energy in the first four bounces for each of the masses. As can be seen, the relationship between incident energy and measured energy, whilst not linear, is at least continuous for each of the ball sizes. However, there is clearly also an effect of ball radius, since the curves for each of the ball sizes are not continuous. The plots are shown at two scales on the ordinate so that the trends at low incident energy can be more clearly seen.

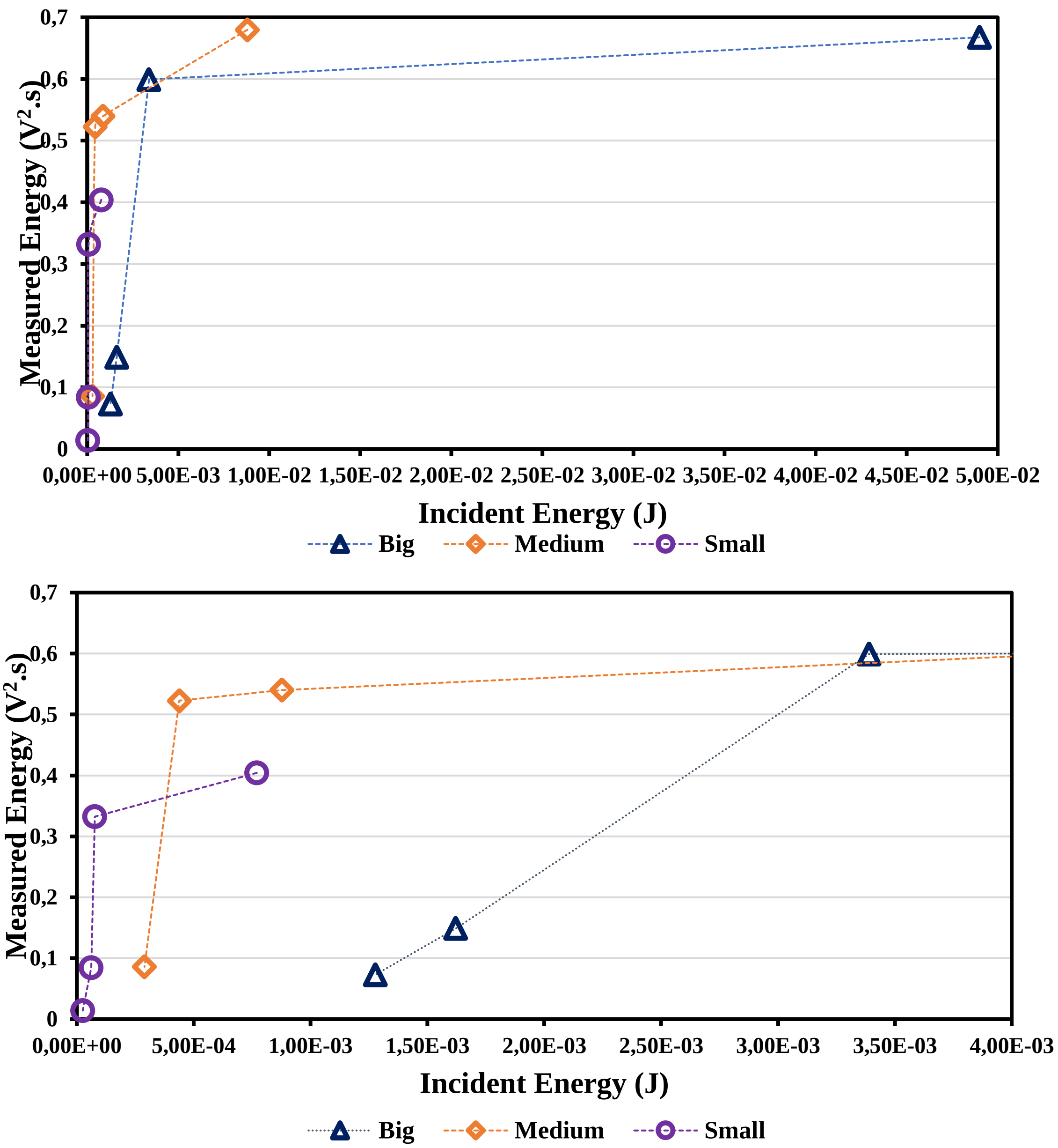


Fig. 5: Plot of measured energy vs incident energy in the first four bounces for all ball sizes dropped on the solid cylinder from 30cm.

3.2 Pipe

Fig. 6 show typical records of the first 2 seconds of AE signal for balls dropped from 30cm height. As can be seen, just as with the solid cylinder, the ball bounces are characterised by a burst signal of duration of about 0.1s, the peak of the burst reducing with successive bounces.

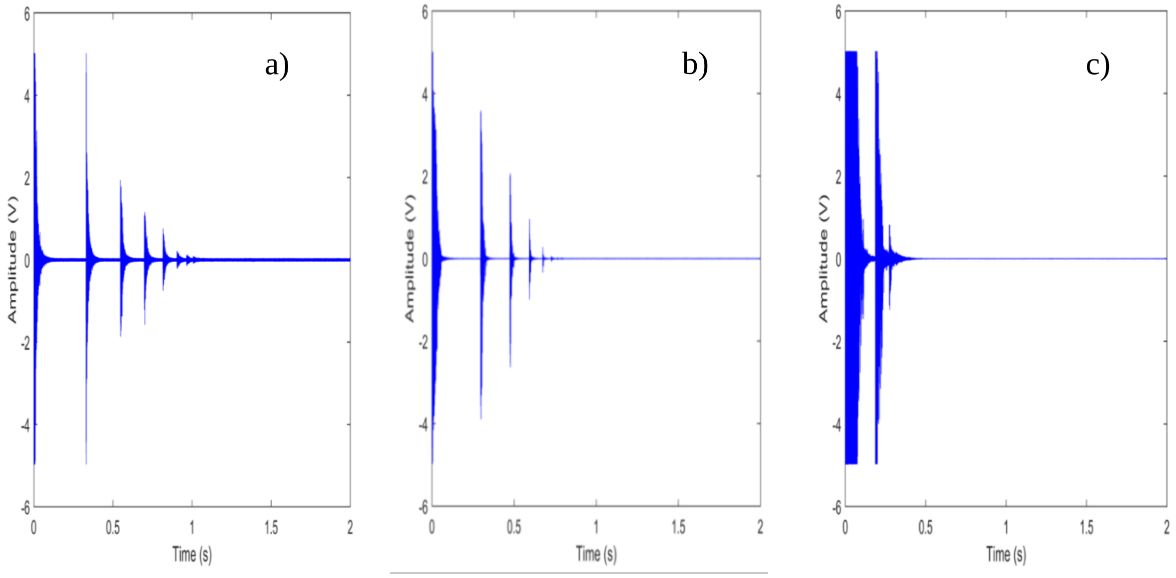


Fig. 6: Typical long-timescale AE signal for balls dropped from 30cm height a) 0.3g b) 3g c) 17g for sensor at 0.5m on the 2m pipe.

A comparison of Fig. 6 with the cylinder equivalent (Fig. 3) shows that the amplitude is a little higher for the pipe, although there are fewer bounces, somewhat further apart. It might be noted that the heaviest ball (Fig. 6c) has saturated the preamplifier and that the actual signal will be somewhat higher than depicted. The saturation seen in Fig. 6c was expected as is usually the case in applications with strong AE-sources.

Fig. 7 shows the first 100 µs around first wave arrival at the first sensor for typical raw AE time series recorded at S1, on the pipe (first wave arrival) for three ball sizes dropped from 30cm height. Comparison with the equivalent signals for the solid cylinder (Fig. 7 with Fig. 4) shows the records for the pipe to be more complex, also, it can be seen that each first arrival is again characterized by a low amplitude component followed by a high amplitude component, which contains the peak amplitude.

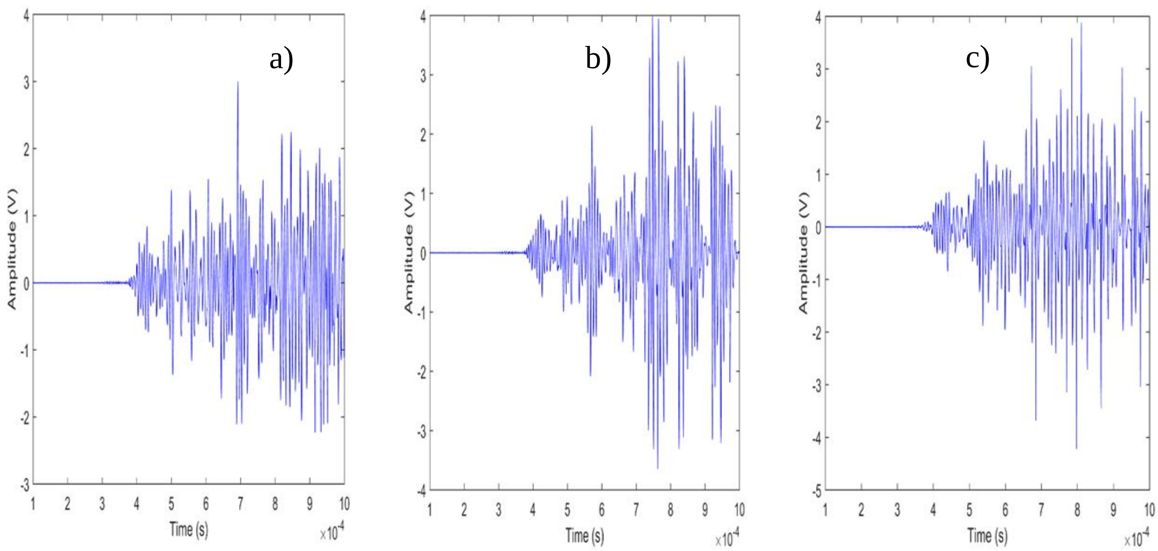
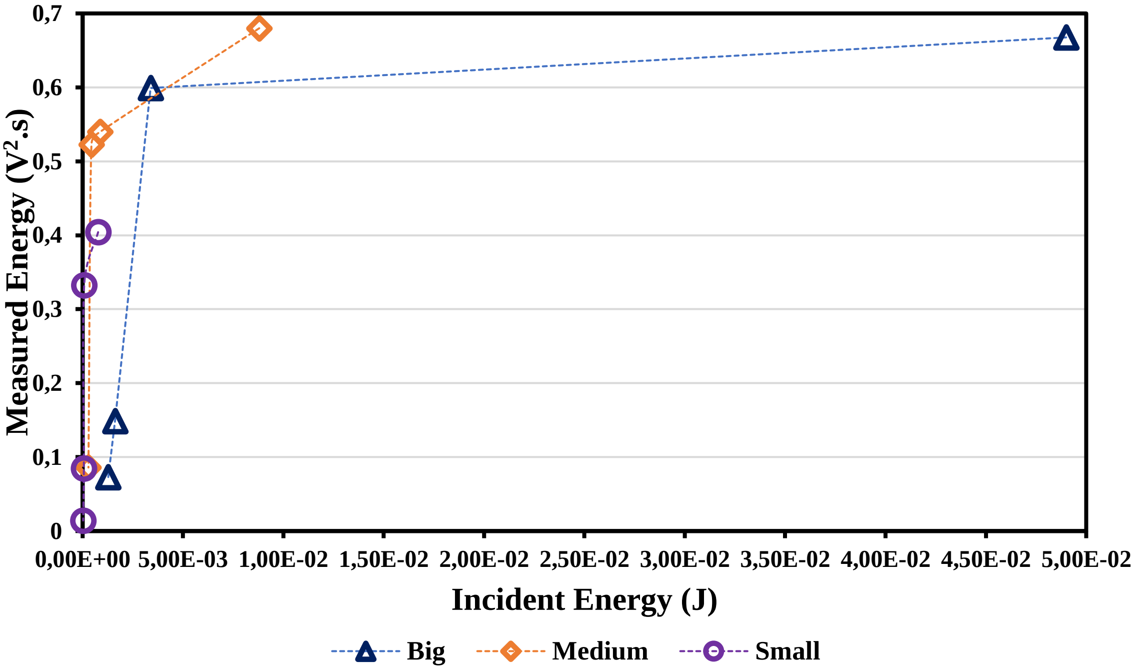


Fig. 7: Typical raw AE time series recorded at S_1, on the pipe (first wave arrival) for three ball sizes dropped from 30cm height (a – 0.3g, b – 3g, c –17g.

Figs. 8 and 9 show plots of measured energy vs. incident energy for the first four bounces for balls dropped onto the reference object and onto the pipe.



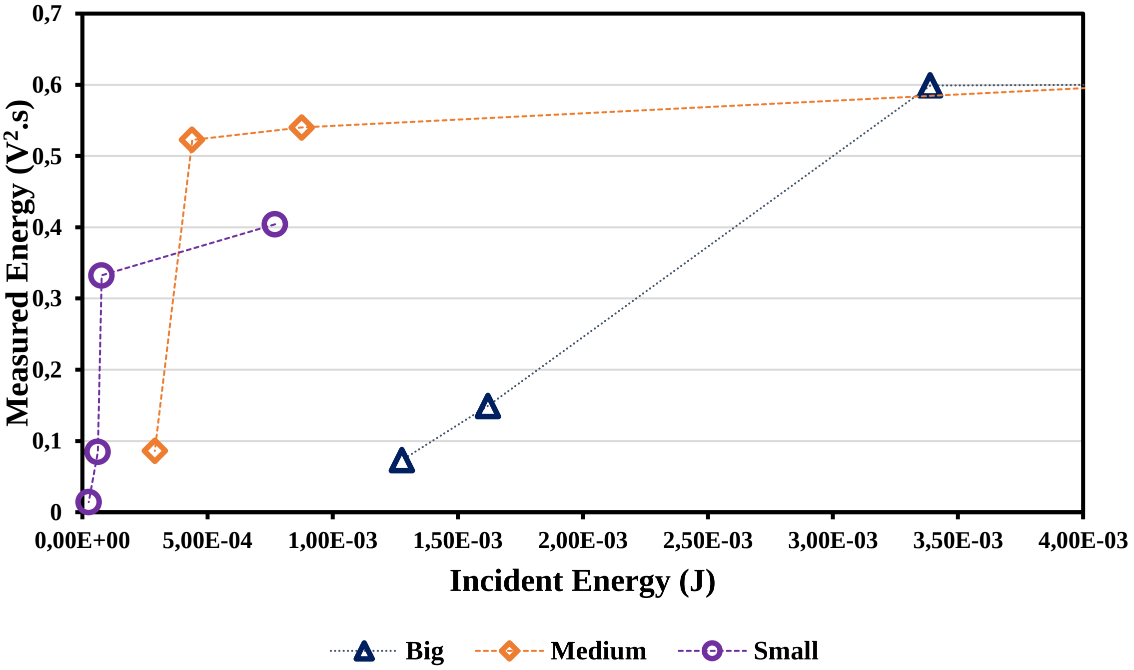
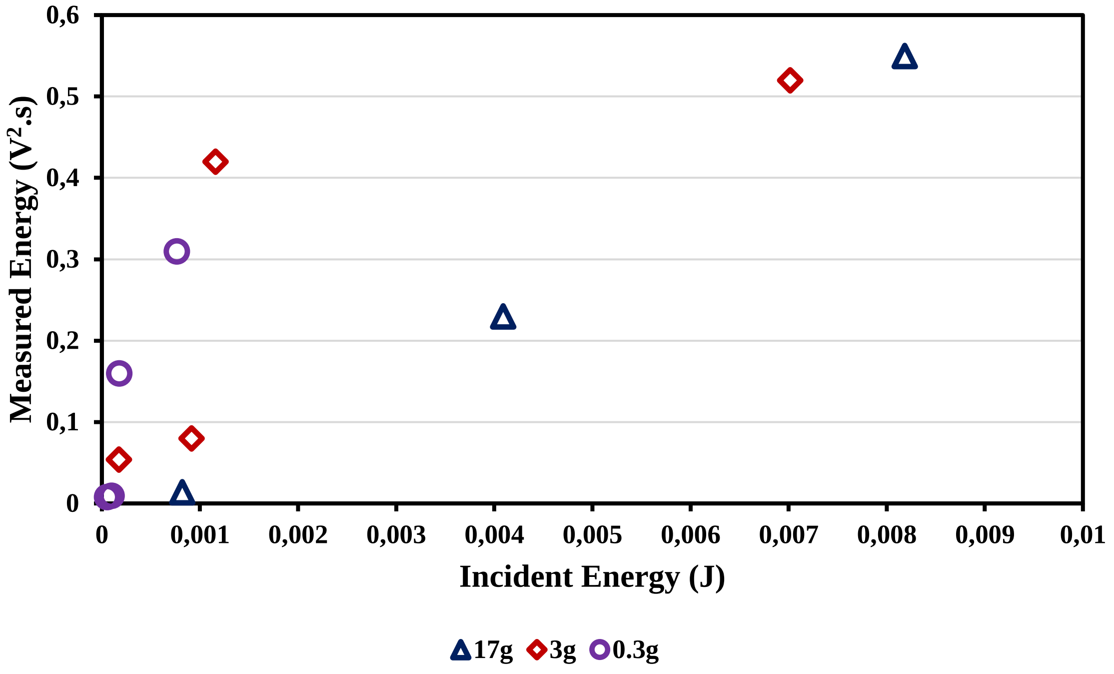


Fig. 8: Plot of measured energy vs incident energy in the first four bounces for the three ball sizes dropped from 30cm height onto the cylinder.



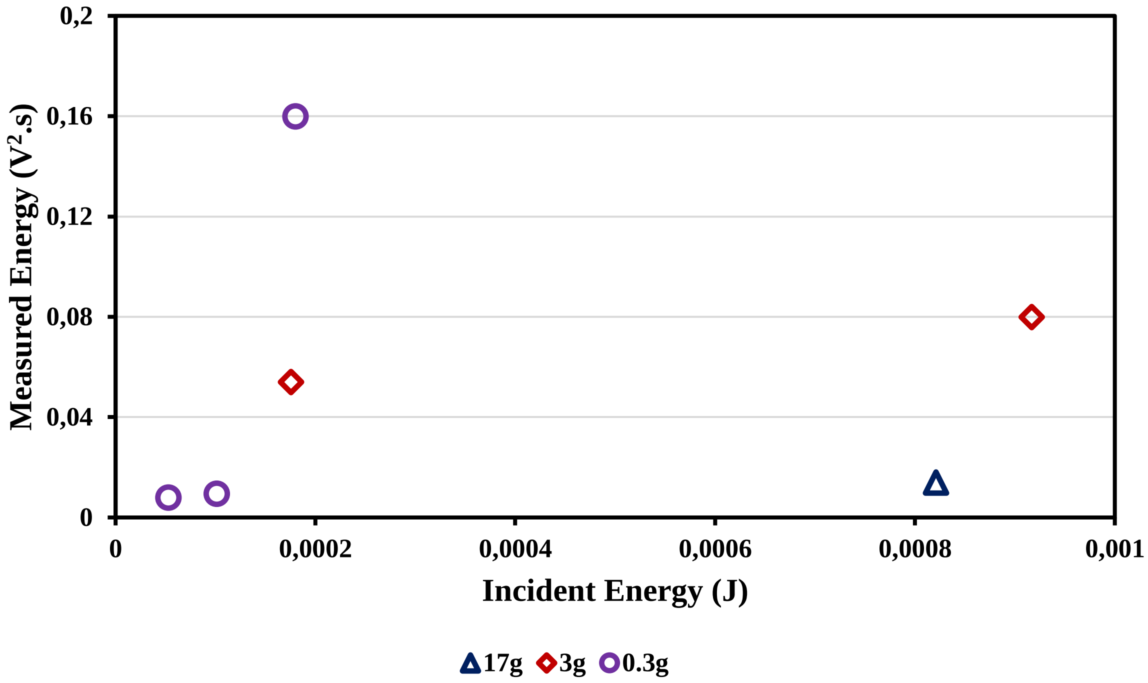


Fig. 9: Plot of measured energy vs incident energy in the first four bounces for the three ball sizes dropped from 30cm height onto the pipe.

From Figs. 8 and 9, it is clear that the pipe experiments show similar general behaviour to those on the solid cylinder, i.e. that the measured energy increases with incident energy, but that the rate of increase is lower for the heavier masses (and radii). This is most likely to be due to the fact that the heaviest masses are have enough momentum to displace the plate if they do not land directly above the contact line between plate and pipe.

Figs. 10 and 11 show plots of measured energy vs incident energy for the first bounce for each of the ball sizes for both the reference object and the pipe. As already observed, the mass (or perhaps the radius) of the ball does not lead to the expected linear increase in measured AE energy and this effect is even more marked for the pipe than it was for the solid cylinder.

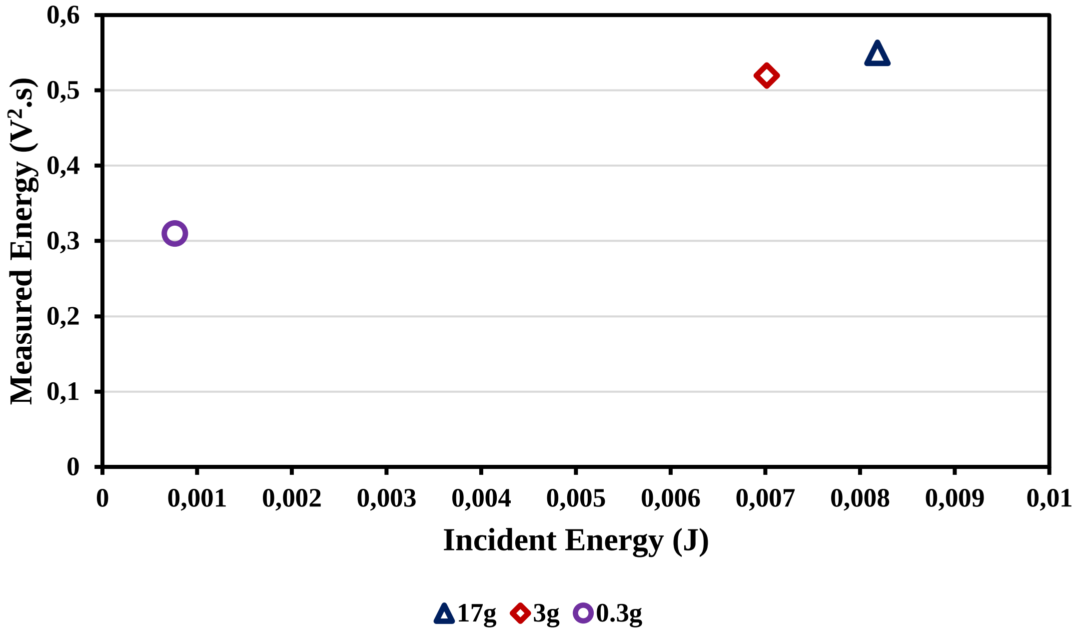


Fig. 10: Plot of measured energy vs incident energy in the first bounce for the three ball sizes dropped from 30cm height onto the cylinder.

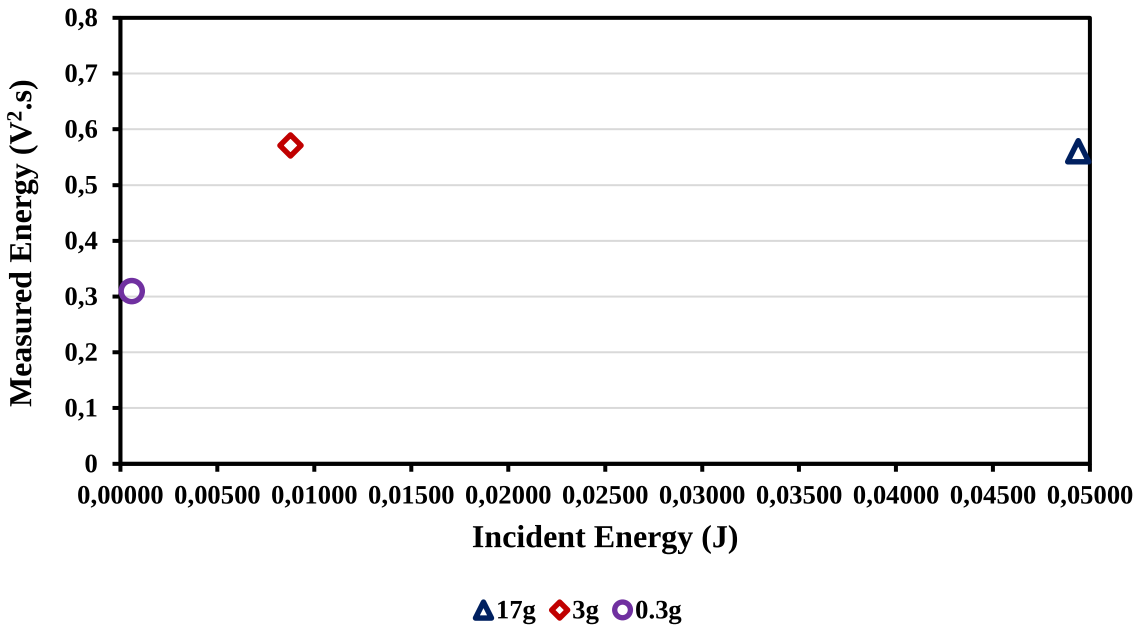


Fig. 11: Plot of measured energy vs incident energy in the first bounce for the three ball sizes dropped from 30cm height onto the pipe.

4. Simulation result and analysis

Just as with the corresponding experiments, the simulated results were recorded as time series, which start when the source is activated. The stress time signals obtained from the simulations at S_1 for 0.3g, 3 and 17g balls dropped from 0.3m heights is shown in Fig. 12 for the first 2 seconds. Comparing these with the corresponding experiments (Fig. 6) shows that the duration of the individual bounces is far longer in the simulations, most noticeably for the lightest ball. This can be attributed to the undamped reverberation of the AE wave in the simulations.

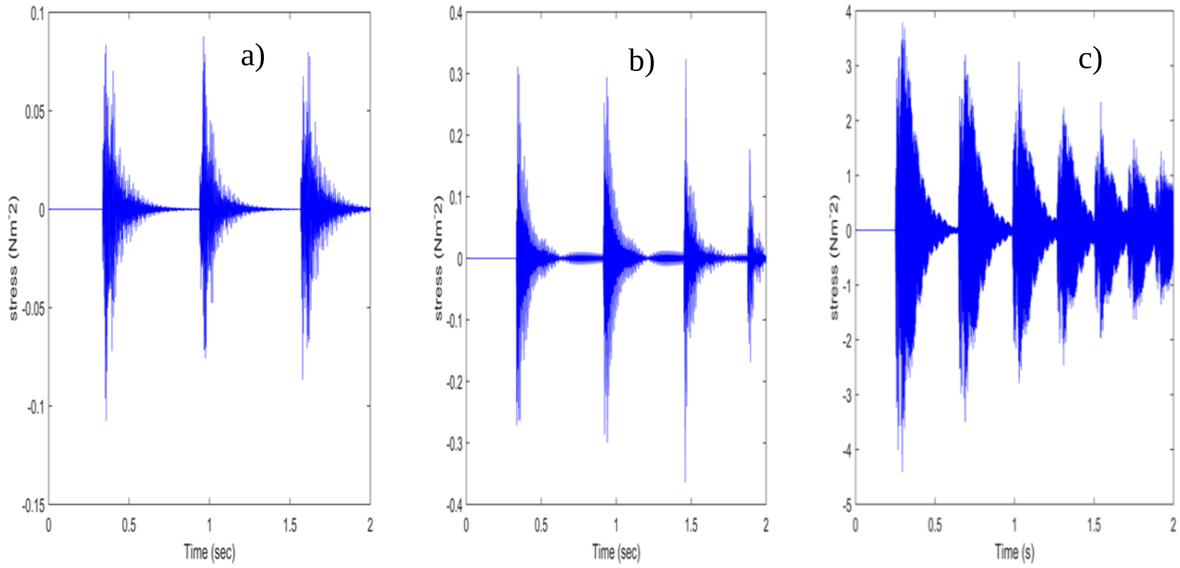


Fig. 12: Time series of Cauchy stress for virtual sensors at 0.5m from the simulated source on a pipe for balls dropped from 30cm height a) 0.3g b) 3g c) 17g.

Fig. 13 show the stress time signals for the first bounce for the plots shown in Fig. 12, it can be seen that the general amplitude increases with ball mass. Also, in contrast with the measurements, the increase in measured energy with incident energy is continuous across all simulations.

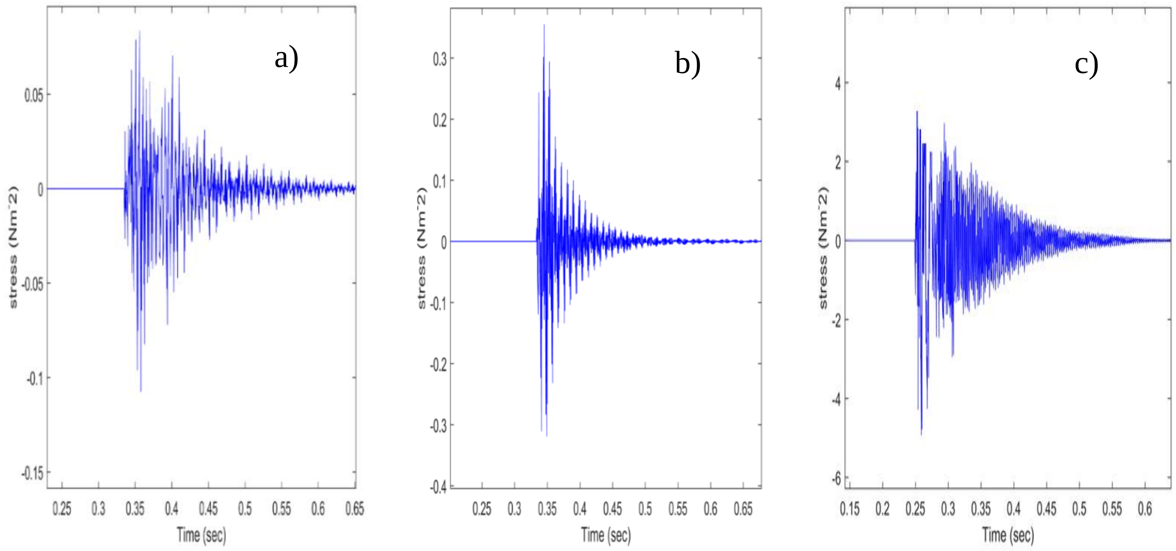


Fig. 13: Raw medium time series of Cauchy stress for virtual sensors at 0.5m from the simulated source on a pipe for balls dropped from 30cm height a) 0.3g b) 3g c) 17g.

Fig. 14 shows a plot of the simulated energy vs incident energy in the first four bounces dropped from 30cm height for the three ball sizes. It can be seen that in contrast with the measurements, there is very little difference in calculated incident energy between bounces, which is not surprising, since the coefficient of restitution for the simulations is unity.

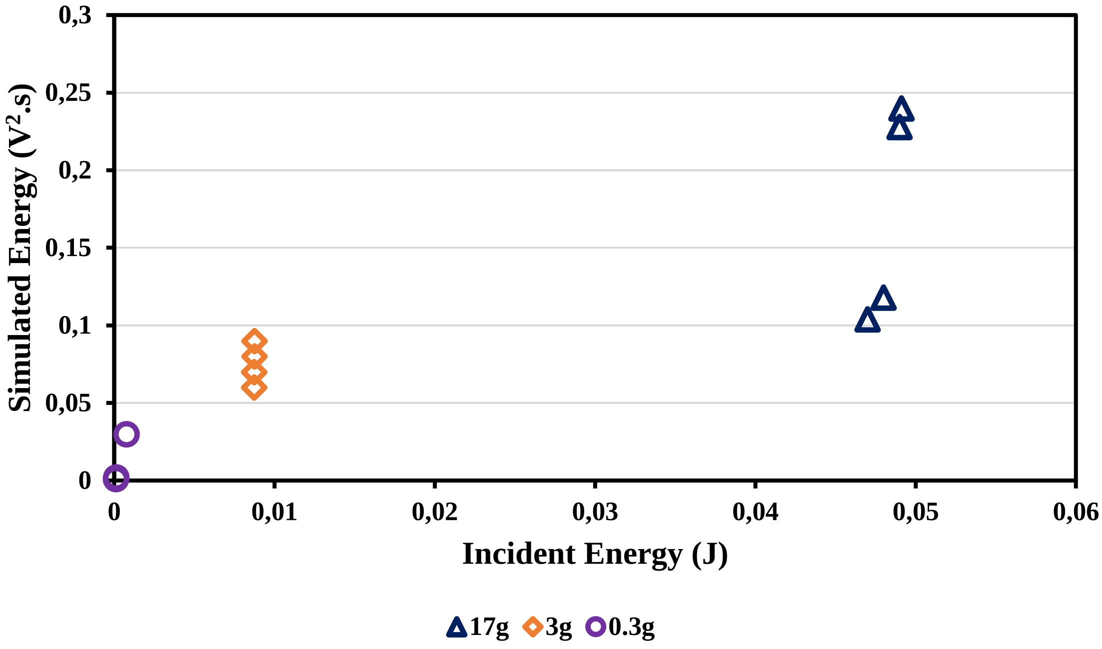


Fig. 14: Plot of simulated energy vs incident energy in the first four bounces dropped from 30cm height for the three ball sizes.

5. Conclusions

The ball drops onto the solid cylinder produced signals in which the first arrival and several rebounds could be discerned over a period of around 1 second. Each impact produced a burst of duration around 0.1 second, sufficient time for multiple reflections from the bottom face and edge of the cylinder. Despite this, there were clear relationships between the incident energy of the dropped object and the measured AE energy, confirming that these would be suitable sources to give a model for practical mechanical disturbances on the pipe.

The experimental and simulation results show that the relationship between measured or simulated energy and estimated incident energy increased continuously, and the differences could be attributed to the practical aspects of the experiments, including changes in coefficient of restitution associated with plastic deformation.

The experiments and simulations exhibited the expected behaviour with a burst of AE signalling the first landing and several subsequent bursts corresponding to the ball bouncing upwards and returning to the surface. In comparison with the equivalent experiments on the flat cylindrical surface, the ball drops on the pipe exhibited a longer burst with each bounce and somewhat more erratic behaviour with subsequent bounces.

Finally, although there was some suggestion that the heavier ball impacts might have involved plastic deformation, such events would be of little interest to a pipeline operator. Mechanical interactions which are of industrial interest are likely to involve such sources as excavators, drills or fishing gear and there would need to be a way of determining the severity of the event in terms of damage to the pipe.

6. References

[1] Haastrup, P. and Brockhoff, L.H., 1991. Reliability of accident case histories concerning hazardous chemicals: an analysis of uncertainty and quality aspects. *Journal of hazardous materials*, *27*(3), pp.339-350.

[2] Shehadeh, M., Steel, J.A. and Reuben, R.L., 2006. Acoustic emission source location for steel pipe and pipeline applications: the role of arrival time estimation. *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, *220*(2), pp.121-133.

[3] Vidya Sagar, R., Raghu Prasad, B.K. and Sharma, R., 2012. Evaluation of damage in reinforced concrete bridge beams using acoustic emission technique. *Nondestructive Testing and Evaluation*, *27*(2), pp.95-108.

[4] Nivesrangsan, P., 2004. *Multi-source, multi-sensor approaches to diesel engine monitoring using acoustic emission* (Doctoral dissertation, Heriot-Watt University).

[5] Webster, J., Marinescu, I., Bennett, R. and Lindsay, R., 1994. Acoustic emission for process control and monitoring of surface integrity during grinding. *CIRP annals*, *43*(1), pp.299-304.

[6] Roberts, T. and Talebzadeh, M., 2003. Acoustic emission monitoring of fatigue crack propagation. *Journal of constructional steel research*, *59*(6), pp.695-712.

[7] Berkovits, A. and Fang, D., 1995. Study of fatigue crack characteristics by acoustic emission. *Engineering Fracture Mechanics*, *51*(3), pp.401-416.

[8] Shehadeh, M.F., 2006. *Monitoring of long steel pipes using acoustic emission* (Doctoral dissertation, Heriot-Watt University).

[9] Ding, Y., Reuben, R.L. and Steel, J.A., 2004. A new method for waveform analysis for estimating AE wave arrival times using wavelet decomposition. *NDT & E International*, *37*(4), pp.279-290.

[10] Zelenyak, A.M., Hamstad, M.A. and Sause, M.G., 2015. Modeling of acoustic emission signal propagation in waveguides. *Sensors*, *15*(5), pp.11805-11822.

[11] Sause, M.G. and Richler, S., 2015. Finite element modelling of cracks as acoustic emission sources. *Journal of nondestructive evaluation*, *34*(1), pp.1-13.

[12] Sause, M.G., Hamstad, M.A. and Horn, S., 2012. Finite element modeling of conical acoustic emission sensors and corresponding experiments. *Sensors and Actuators A: Physical*, *184*, pp.64-71.

[13] Abolle-Okoyeagu, C.J., 2019. *Acoustic emission monitoring of pipes: combining finite element simulation and experiment for advanced source location and identification* (Doctoral dissertation, Heriot-Watt University).

[14] Prosser, W.H., Hamstad, M.A., Gary, J. and OGallagher, A., 1999. Reflections of AE waves in finite plates: finite element modeling and experimental measurements. *Journal of Acoustic Emission*, *17*(1-2).

[15] Okoyeagu, J.A., Torralba, J.P., Chen, Y. and Reuben, R., 2014. Acoustic emission source identification in pipes using finite element analysis. In *Proc. of 31 Conf. on European Working Group on Acoustic Emission* (pp. 3-5).