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Construction noise and vibration monitoring on the web

1. Gregory Bracci, Business Development Manager - Urban/Industrial, Brüel & Kjær EMS Inc.
2. Phil Stollery, Global Product Marketing Manager, Brüel & Kjær EMS.

Abstract: Noise from large construction projects can be a nuisance for nearby communities. Vibration from activities like pile driving, concrete crushing and tunneling can also create nuisance but may also risk structural damage. Increasingly, both noise and vibration are significant factors surrounding a construction project. If not managed properly they can lead to project delays, further prolonging the nuisance and significantly increasing project cost. To help mitigate these risks, contractors are now using continuous noise and vibration monitoring to ensure that the impact from construction activity is kept within guidelines.

This paper looks at how continuous real time monitoring of noise and vibration can be used to help manage community impact and reduce the risk of structural damage. It will look at legislation and best practice both in Canada and in other parts of the world. Presenting the concept of environmental capacity it also shows how engaging communities, setting expectations and building trust can be effective way of mitigating impact.

The paper goes on to highlight new technology that is in use in Canadian construction sites which uses the approaches discussed above to help manage compliance and reduce risk.

1. Introduction

Amongst our rapidly expanding communities construction sites have become ubiquitous. In many cases communities accept the impact from construction knowing that ultimately it delivers a benefit and is only a temporary issue. However some projects, such as the construction of large infrastructure like light rail systems, sewers, freeways and high speed rail links can continue for prolonged periods, sometimes taking over 5 years. Furthermore, infrastructure is built to serve expanding communities and is often located close to densely populated areas. This mix of issues can lead to problems for all parties if it is not properly managed.

This paper presents Environmental Capacity as important consideration for large construction sites and by doing so highlights a number of ways in which real time web based noise and vibration monitoring can be used to manage Environmental Capacity throughout the life of a large construction project.

2. What is Environmental Capacity?

Brüel & Kjær EMS has spent over 20 years working with the worlds airports to help manage noise issues with the surrounding communities. Throughout that time we have used the concept of Environmental Capacity to articulate the issues differently and to develop innovative solutions to

help deal with the problem. Environmental capacity is an equally valid concept for construction sites as well as other facilities with noise issues.

The term environmental capacity was first used in the 1980's by Pravdic [1] and later adopted by the United Nations group of experts on scientific aspects of marine Environmental Protection. Their definition was:

*"**Environmental capacity is "a property of the environment and its ability to accommodate a particular activity or rate of an activity….without unacceptable impact**"*

The definition we use is a little simpler

*"**Environmental Capacity is the mandate for growth provided by the community**"*

The concept in airports is built around an airport's need for growth. In order to meet increasing demand an airport will build physical capacity in the form of a new runway or a terminal expansion etc. These provide increases in physical capacity to help service the increasing demand. There is another constraint which is Environmental Capacity; and depending on where on the Y axis the red line sits determines if it is constraining the airport. In Europe every large international airport is environmentally constrained which prevents full utilization of the available physical capacity. As you'll see later in this paper, you can invest in Environmental Capacity to raise the red line and to enable more of the physical capacity to be used.

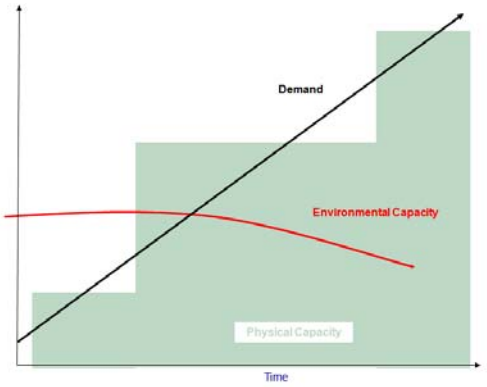

Figure 1: Environmental Capacity

There is one other property of Environmental Capacity that needs to be considered which is that there is a decay effect over time. The measures you take to increase the environmental capacity become stale and it's necessary to continue investing and taking innovative measures in order to maintain the current Environmental Capacity.

However, Environmental Capacity is not really about growth, it's about change, and this is where it applies to construction. A construction site brings about a change in the environment and even though it will be temporary, if there isn't sufficient Environmental Capacity then it can spell trouble for the construction project.

3. How do you build Environmental Capacity?

How you can increase Environmental Capacity becomes apparent when you consider the factors affecting it. Our first law of Environmental Capacity states that it depends on the difference between the tolerance of the surrounding community and the environmental impact. Clearly the less environmental impact there is, the smaller the problem and the greater the Environmental Capacity. Reducing Environmental Impact is the factor most frequently addressed. It is the other factor of community tolerance that is equally as important. It shows that if you can

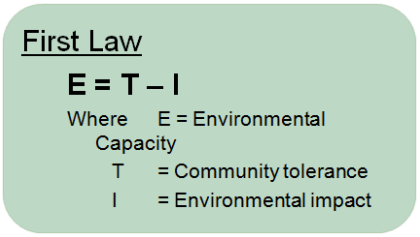

Figure 2: The 1st law of Environmental Capacity

increase the community's tolerance, then you can also increase Environmental Capacity. Understanding community tolerance is therefore key and increasing it provides a second string to the bow of building Environmental Capacity.

Community Tolerance is represented by the Second law of Environmental Capacity which states that it is the difference between Expectation and Perception. Thus community tolerance can be increased by setting correct expectations and managing perception of the impact – and in turn increasing Environmental Capacity.

Having defined the factors influencing Environmental Capacity it then becomes clear what measures can be put in place to increase it. Before we cover those, we should see what can happen when there is insufficient Environmental Capacity.

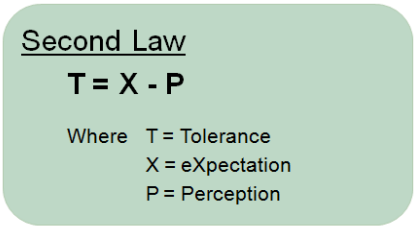

Figure 3: The 2nd law of Environmental Capacity

4. An example of insufficient Environmental Capacity - The West Toronto Diamond

The West Toronto Diamond project consisted of the construction of an underpass to separate GO transit commuter rail lines and Canadian Pacific Railway's (CP's) freight trains along GO Transit's Georgetown line to the west of Toronto. The north-south tracks to and from Georgetown are being lowered so that they run under CPR's North Toronto line. Construction started in January 2009 and was originally scheduled for completion early 2011.

Figure 4: Construction site surrounded by communities

Early in the project piling activities started and almost immediately complaints were made by the communities - "*Residents felt vibrations in their house, which caused them physical and personal disruption and irritation*" [2]. Within three months a number of initiatives were formed against the project. Community rallies were organized to protest about the construction noise and vibration levels and GO Transit's failure to deal with them in a reasonable manner. A Facebook page, Citizens United against West Toronto Diamond Pile Drivers was opened and a complaint was filed on behalf of the community by the West Toronto Diamond Community Group.

The Canadian Transport Act of 2007 requires the Canadian Transport Agency, (CTA), to investigate all complaints made regarding noise and vibration from railway operations and construction. After consideration, in October 2009 the CTA decided in favor of the community group ruling that "*GO Transit was in breach of its obligation to cause only such noise and vibration as is reasonable during pile driving activities at the site*" [3]. Whilst recognizing the long term benefits for works to progress, the ruling emphasized the need to balance these against the interests of local residents impacted by noise and vibration. It went on to state that insufficient measures had been taken to reduce noise and vibration impact and proposed a range of corrective measures limiting working hours, stipulating the use of low noise pile driving hammers, mandating continuous noise and vibration monitoring and establishing a range of communications measures for the community.

- Stipulating the use of different pile-driving hammers and techniques such as; replacing impact hammers with a lower noise alternatives such as a vibratory hammer or a Giken hammer; operating hammers with reduced power; implementing noise shrouds and deploying moveable noise barriers
- limiting work hours for pile-driving activities to 08:00 – 16:00 weekdays only
- Implementing a continuous noise and vibration monitoring program with weekly reporting.
- Establishing a range of communication measures including daily updates to a website showing activity schedules, 2 weeks notice to any schedule changes, email and phone complaint centers responding to complaints within minimum 48 hours and posting weekly noise and vibration reports on the web for review.

Figure 5: Silent piling using a Giken hammer

The ruling effectively required the contractor to use quieter equipment for less time, however the equipment is less efficient and more expensive. The overall effect for the project was to extend it to 2014 and increase costs significantly.

It is interesting to put these measures in terms of the laws of Environmental Capacity.

Initiative	Contribution to Environmental Capacity
Changes to piling hammers	Reduce impact
Limiting work hours	Reduce impact
Implement continuous noise and vibration monitoring with weekly reporting	Reduce impact, set expectation and improve perception
Daily updates to a website showing activity schedules, 2 weeks' notice to any schedule changes	Set expectation
email and phone complaint centers responding to complaints within minimum 48 hours and	Manage perception
posting weekly noise and vibration reports on the web for review	Set expectation and manage perception

Each initiative goes towards addressing one or more aspects of Environmental Capacity with the intention of building sufficient Environmental Capacity to enable the community to accept the temporary change to the environment.

5. Legislation around construction noise and vibration

Noise and Vibration Legislation is one way in which Environmental Capacity can be built prior to a project commencing. Mandating specific measures that can be accommodated and costed at the planning stages of a project is certainly a more efficient and often more effective way of dealing with the situation. However whilst legislation exists and is enforced around ground vibration, it is generally not the same situation around noise. This is largely because whereas noise is a community nuisance issue, vibration, whilst also causing nuisance, can cause property damage and is more likely to lead to potential litigation. There follows a review of some examples of legislation in place. This is based on experience and is not meant to be exhaustive.

In Toronto, vibration legislation exists in the form of City By-law No. 514-2008. This mandates continuous vibration monitoring and states the maximum allowable ground vibration in a defined zone of influence.

Toronto Law 514-2008 Prohibited Construction Vibrations	
Frequency of Vibration (hertz)	Vibration Peak Particle Velocity (mm/sec)
Less than 4	8
4 to 10	15
More than 10	25

The law goes on to specify a range of measures including a public communications protocol and complaint handling along the lines specified in the West Toronto Diamond example. Noise is covered by the Toronto Municipal code chapter 591 and an amendment specifically targets construction noise. It prevents operation of any aspect of the construction site between the hours of 7:00pm and 7:00am Monday to Friday, before 9:00am and after 7:00pm on Saturday and all day Sunday. Some exceptions for specific projects are permitted to extend to 11:00pm however [4].

Throughout Europe the German DIN 4150-3 standard [5] is commonly used when ground vibration. This standard provides for different guideline levels based on the type of structure.

Vibration Velocity, v,, in mm/s				
Structural type	**Foundation**			**Plane of floor of uppermost storey**
	Less than 10Hz	**10-50Hz**	**50-100Hz**	**Frequency mixture**
Commercial, Industrial or Similar	20	20 to 40	40 to 50	40
Dwellings or Similar	5	5 to 15	15 to 20	15
Particularly Sensitive	3	3 to 8	8 to 10	8

Similarly Swiss standards [6] provide different limits for different types of structure such as concrete, masonry, wooden beams and brick walls. Perhaps the most up to date standard in Europe is the British Standard BS7385 [7] [8] which was revised in 1993. Part 2 covers structures defines a limit of 15mm/s at 4Hz rising to 20mm/s at 15Hz and increasing to 50mm/s at 40Hz and above.

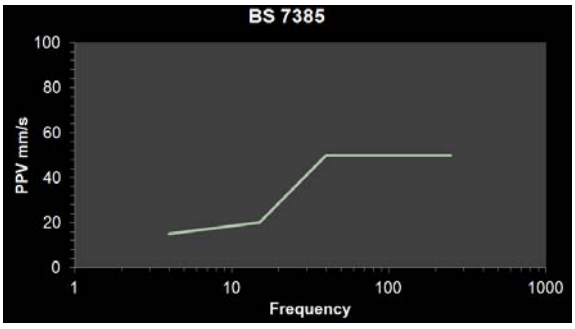

Figure 6: BS 7385 Vibration limits

Where standards start to differ significantly is when assessing the human response to vibration. Whereas Peak Particle Velocity is the metric used when assessing structural damage, it is Vibration level or Vibration Dose Value that is used to determine nuisance from vibration. The vibration level is the RMS level represented in decibels relative to a reference value. It is often presented in octaves or 1/3rd octaves.

The Vibration Dose Value, measured in units of $m/s^{1.75}$ is defined in BS: 6472:2008. The VDV is an energy averaged vibration level similar to Leq but with a time dependency making it much more sensitive to changes in vibration level than changes in duration. VDV must be assessed separately in the vertical axis during the daytime and the longitudinal and transverse axes during nighttime. This better reflects the response to a human standing during the daytime and lying down during night. Most often VDV is applied for monitoring vibration response to long term exposure such as assessing vibration from railways rather than construction projects.

A different type of legislation is appropriate where vibration may affect sensitive equipment and this is particularly important for any construction activity located near hospitals, research institutes and industrial facilities that house imaging equipment such as silicon wafer plants. Magnetic Resonance Imaging Equipment is extremely sensitive to vibration and where there is a risk of impact, vibration should be monitored. In this case vibration is assessed in terms of acceleration and requires accelerometers rather than the less sensitive geophones typically used around construction sites. An example of levels specified around a Nuclear Magnetic Resonance device are shown below.

Frequency	No single peak greater than
Greater than 50 Hz	509 µg
20-50 Hz	509 µg
15 to 20 Hz	20000 µg
10 to 15 Hz	100 µg
5 to 10 Hz	50 µg
Less than 5 Hz	5 µg

In addition, an absolute limit of 0.1g above 3Hz is stated as exceedances could cause damage to the instrument and pose a serious threat to the health and safety of the operator.

6. How can monitoring technology help?

A real time web based noise and vibration management system is an effective tool to help manage Environmental Capacity; delivering benefits in terms of reducing noise impact, setting community expectations and improving tolerance. Monitoring systems have been around for a number years but three important aspects are only now becoming available

1. Real time data collection and presentation
2. Integrated noise and vibration solutions
3. Effective engagement with communities

6.1 Real time data collection and presentation

Improvements in monitoring technology, communications and computer technology have all helped to make real time monitoring a practical solution. Until recently a monitoring system would use instruments in the field to capture data and transfer that data regularly, typically overnight, to a central database. An operator would periodically refer to the database, perhaps printing off a weekly report which summarized the measurements taken.

Such an approach has some uses but is only able to show what happened in the past. This might be useful when investigating complaints or deciding how to operate in the future. However, once you can receive information in real time systems can now immediately create an alert should a noise or vibration limit be exceeded. This means the site operator, it's consultant or any other party can take immediate action to stop the activity and thereby reduce the environmental impact.

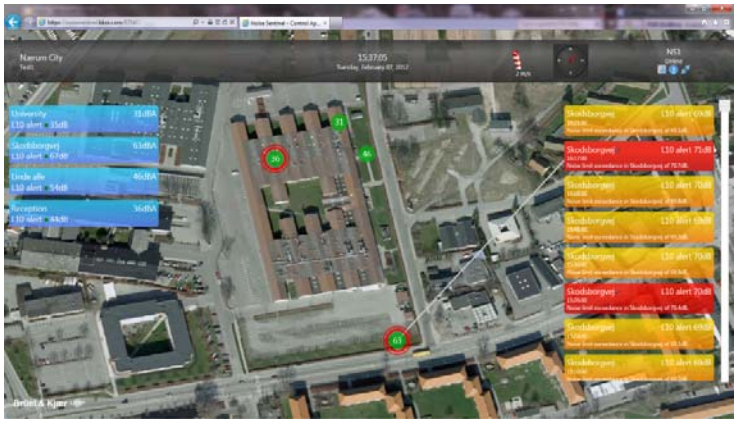

Figure 7: Real time display enables real time mitigation

Depending on legislation, such an approach may enable breaches to be prevented rather than just reporting on when they did; something which is in everyone's interest.

6.2 Integrated noise and vibration solutions

Equipment suppliers typically range from noise instruments to vibration instruments with some suppliers doing both. As suppliers start to take a market based view, rather than a technology based view, we begin to see solutions that add great value to particular business segments. Hence, for the construction industry, integrated noise and vibration solutions that stop at providing instruments, but deliver what the construction project actually need which is

- Continuous assessment 24/7
- Warning & notification of high levels
- Compliance reporting
- Capability to investigate the cause
- Remote access

As these solutions develop further we can expect them to develop additional capabilities relevant to managing the environmental impact around construction sites.

6.3 Effective engagement with communities

Referring back to the discussion of Environmental Capacity we can see that there is a lot that can be achieved through managing community expectations over when and where work will take place as well as managing their perception of the noise. Urban communities contain a lot of noise sources and are extremely complex acoustically. Many times, loud noise levels have no connection with a construction site yet the public may perceive them as being so. Publically available tools accessed over the web help to manage the correct perception of the noise being measured.

Technology now enables monitoring systems to share selected data in real time with communities so that they can see current noise levels and listen to the noise to determine if it really is construction noise that is causing it. Reviewing historical noise levels helps the public to put the current noise levels in context and viewing it alongside details of what is happening on site set expectations.

Figure 8: Web displays informing stakeholders

Such initiatives builds trust with the community and trust goes a very long way to developing Environmental Capacity.

7. Example: New Sewer project – Ontario, Canada.

Figure 9: Noise and Vibration Monitoring Equipment

This project was commissioned to expand a sewer across 10km of the region through densely populated areas. As such there was significant potential for community noise nuisance, potential structural damage and also effects on local wildlife.

AECOM were appointed consulting engineers for the project which required tunneling underneath the city and surface construction at 15 separate shafts along its route. Due to the proximity to the community, continuous noise and vibration monitoring was mandated by the projects environmental impact assessment.

Integrated noise and vibration monitors continuously capture data from 16 locations across the project and transmits the results in real time over secure internet links. Live alerts are sent to the project team whenever noise or vibration limits are exceeded at the site. With this information, the AECOM team can quickly assess the construction noise and vibration and address the issues with the construction manager to mitigate the impact on area residents. This approach can also provide significant cost savings for the client, when compared to the expense of having field technicians take daily measurements.

Comprehensive compliance reporting also captures exactly what was happening and provides a valuable source of information when investigating and responding to complaints from the community.

The system has been in place since August 2011 and will continue throughout the project which is due to complete in 2014

8. Conclusion

This paper has introduced the concept of Environmental Capacity and shown how the concept can relate to large construction projects. Illustrating the concept with an example where there was insufficient environmental capacity it shows how integrated noise and vibration monitoring

systems have now developed to enable construction contractors, consultants and project owners to actively manage the Environmental Capacity to minimize project risk and impact on surrounding communities.

Acknowledgments

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[5] DIN 4150-3 (1999-02) Structural vibration - Effects of vibration on structures

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[7] BS 7385-1 Evaluation and measurement for vibration in buildings Part 1: Guide for measurement and evaluation of their effects on buildings

[8] BS 7385-2 Evaluation and measurement for vibration in buildings Part 2: Guide to damage levels from groundborne vibration