Practical approach for controlling blasting vibration and optimizing advance in tunneling

ITAtech activity Group Excavation

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1 >> Preface

This document introduces some guidelines to help make the best use of drill-and-blast (D&B) – techniques in underground tunneling at vibration sensitive locations. Strict vibration limits can considerably restrict D&B work, increase cost or even prohibit its use. Good planning of controlled blasting can often accommodate such restrictions.

This document does not cover vibration measurement methods or pre-estimation of allowed vibration levels, but merely describes practical suggestions of how to utilize vibration measurement in D&B pattern design and detonation control. Second and main target of this document is to introduce a suggestion of global data bypassing format between vibration measurement systems and D&B design programs so that this data would be easily available.

2 >> Blasting generated vibration

Projects execution always seeks to minimize excavation cost while meeting the required programme. Geology may vary a lot during tunnel advance and this can affect the propagation of vibration waves as different materials transmit the waves differently.

Due to the complexity of geology, forecasting of vibration propagation can be difficult. To get an understanding of this, some test blast and measurements can be performed prior to excavation work.

Multiple factors affect the propagation of vibration waves:

- receptor distance from the blast
- rock mass properties, the ability to conduct and absorb the vibration
- changes in rock mass which can cause bending and reflection of vibration waves
- rock mass fracturing and orientation towards the vibration waves
- change of water content or temperature, such as in moraine or frosted soil.

Environment and nearby structures define the allowed vibration limits. Allowed limits are usually set by authorities and sometimes by legislation taking into account factors like:

- type and age of structures
- use of structures (e.g. strict limits for hospitals and certain manufacturing facilities)
- geology (soft moraine, limestone, granite,..)
- construction materials (brick, concrete, wood,…) and basement type
- the reliability of the as-built data of structures.

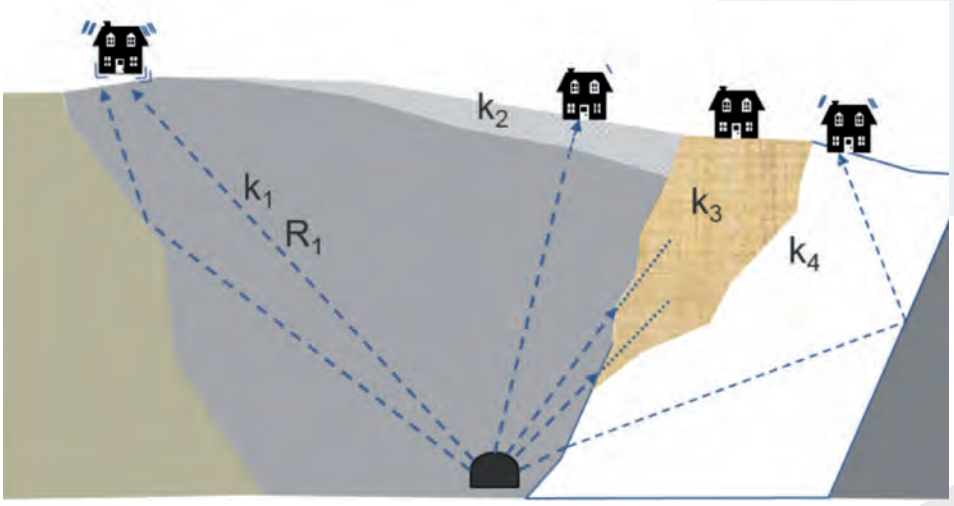

Figure 1 : A simplified illustration of propagation of vibration waves. Factor k indicates different vibration conductivity. Waves propagates straight, can be dampened or can reflect.

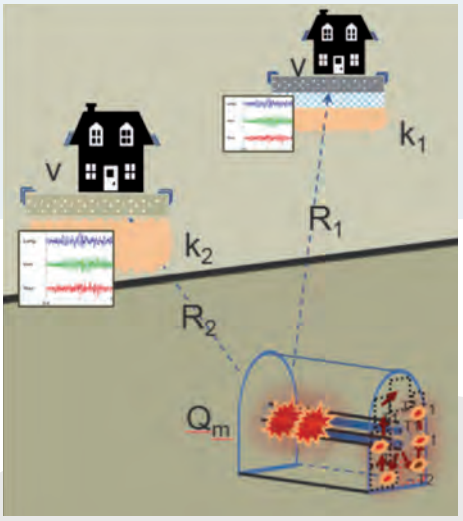

Figure 2 : Blasting generated vibration can be estimated based on maximum instantaneous charge (Qm), rock mass properties to conduct vibration (k) and distance from the blast (R). Realized vibration can be measured from predefined points.

Figure 3 : An example of critical and challenging estimate of allowed vibration level. The structure of an old railroad basement was not exactly known. A crossing twin tube traffic tunnel was excavated using drill-and-blast method by Lemminkäinen Oy. Photo courtesy of city of Tampere.

In general emulsions (bulk, cartridges), ANFOs and pipe charges are used in underground tunnelling blasting. Detonating cord is sometimes used in contour hole blasting as well as connecting detonation from hole to hole.

Hole charges are made from column explosives and primer part, as an example of charge A in Figure 5. The total amount of explosives is calculated as a mass per each charge, as this is typically the minimum amount of momentary kilos that can be blasted. Charges are lightened up towards the contour typically. This can be done by selecting different diameter of cartridges or adjusting emulsion pumping [kg/m] or density.

Two main categories are used for tunneling blasting detonation: impulse detonators or electronic detonators. Impulse detonators offer a limited amount of different numbers as the construction is basically pyrotechnical. A series of 25ms – 6 000ms with 32 different numbers can be considered as typical approach for these. The interval of timing gets longer towards the end of the series as pyrotechnics introduces some spread in timing.

Electronic detonators offer extensive possibilities for timing, as they are freely programmable and do not suffer the limits of pyrotechnics inside impulse detonators. Typical time range is 0ms – 10 000ms. The use of electronic detonators requires manufacture specific programming system. The prize of electronic detonators is however about 10 times the prize of impulse detonators per each.

Blasting of explosives in rock creates vibration to the environment. The more that gets blasted per ignition level, the more vibration will be generated, so the tendency is to limit the amount of explosives per ignition level.

Explosive	Type	Heat [MJ/kg]	Gas [l/kg]	Velocity [m/s]
Gelatine	Cartridge	4.5-5.4	840-900	2500-6000
ANFO	Pump	3.5-4.0	900-1000	2500-3500
Emulsion	Pump, Cartridge	2.5-3.0	850-1000	3000-5000
F-pipe (17 mm)	Pipe Charge	2.4	400	2400
KEMIX A (32 mm)	Cartridge, Pipe	3.8	924	4600-5600

Figure 4 : Some typical explosive characteristic values. Values do vary based on manufacturer and country.

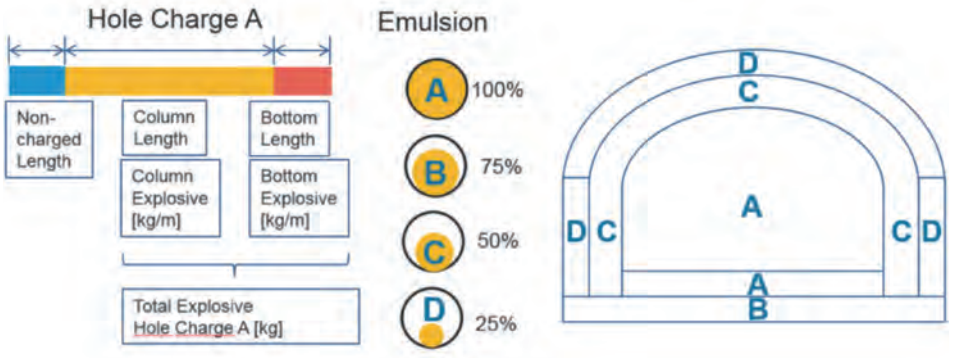

Figure 5 : A simplified example of hole charge 'A' on left, principle of adjusting emulsion amount in middle, and some typical smooth blasting example of applying different charges in a 'construction size' tunnel profile. Values like 1.6 kg/m, 1.2kg/m, 0.8 kg/m and 0.40 kg/m can be found typical.

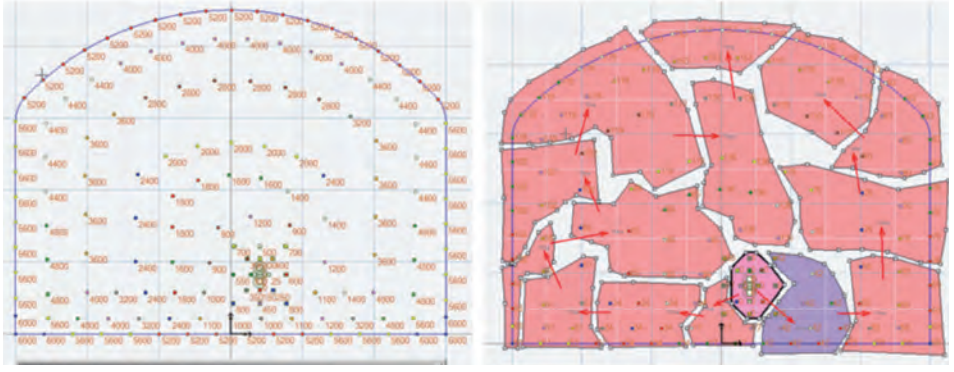

Figure 6 : An example of detonation for 100m2 face. On the left detonation with impulse detonators having maximum momentary of 88kg and blasting 24 holes simultaneously. On the right the same design of holes, but two routes of surface delay units (17ms and 42ms SF-units) added. Momentary restricted to 16,3kg blasting max 2 holes at the same time. Specific drilling 1,51 dm/m3 and specific charge 1,7kg/m3 using emulsion explosives. Round's length 5,2m / hard rock case.

As there is a lack of different numbers in impulse detonators, additional surface delay units can be used in grouping impulse detonators and thus create an offset between same number of detonators. This method extends the usage of impulse detonators. Surface delay units can be connected into 2 or more branches and the timing difference is created at the beginning of the connection between them. This difference is thus maintained towards the end of the connections.

The momentary reporting in the above cases is based on defining hole charges and detonation of the plan.

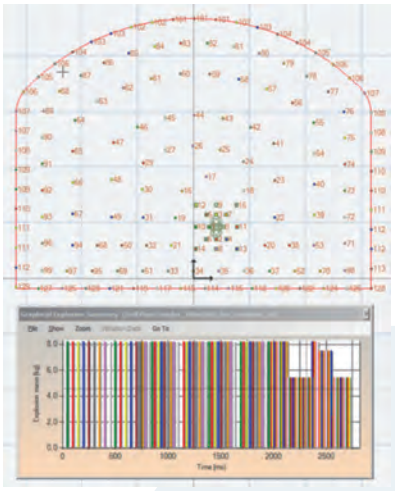

Figure 7 : An example of 100m2 face with electronic detonators. Momentary maximum is 8,2 kg. Each hole is blasted at its individual time.

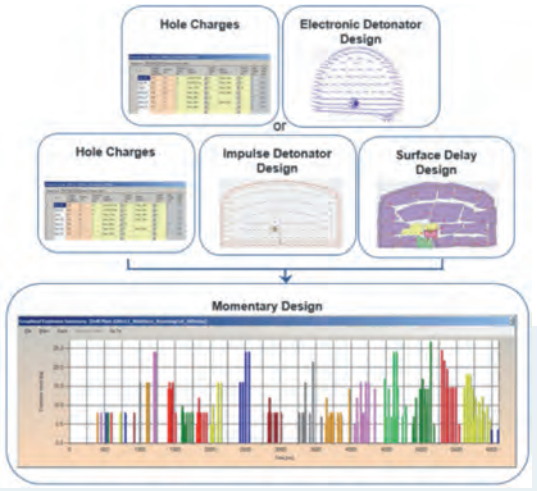

Figure 8 : Defining charges and detonation creates the status of momentary kilos in drill-and-blast design program.

4 >> Vibrating measurements systems

Measurement systems play a vital role in vibration control. Sensors (triaxial seismographs) are attached at critical places, where Peak Particle Velocity (PPV) limit-values have been defined. Sensors are connected wirelessly to a web-server. Sensors start to record when they detect a vibration level over a defined trigger level and record vibration speed [mm/s], vibration amplitude [mm], acceleration[m/s2] and frequency [1/s]. This data is recorded in direction of x-, y- and z- axes. The web-server collects the information and produces vibration reports together with possible overshoot comparison. These reports can then be downloaded straight after the blast by jobsite personnel.

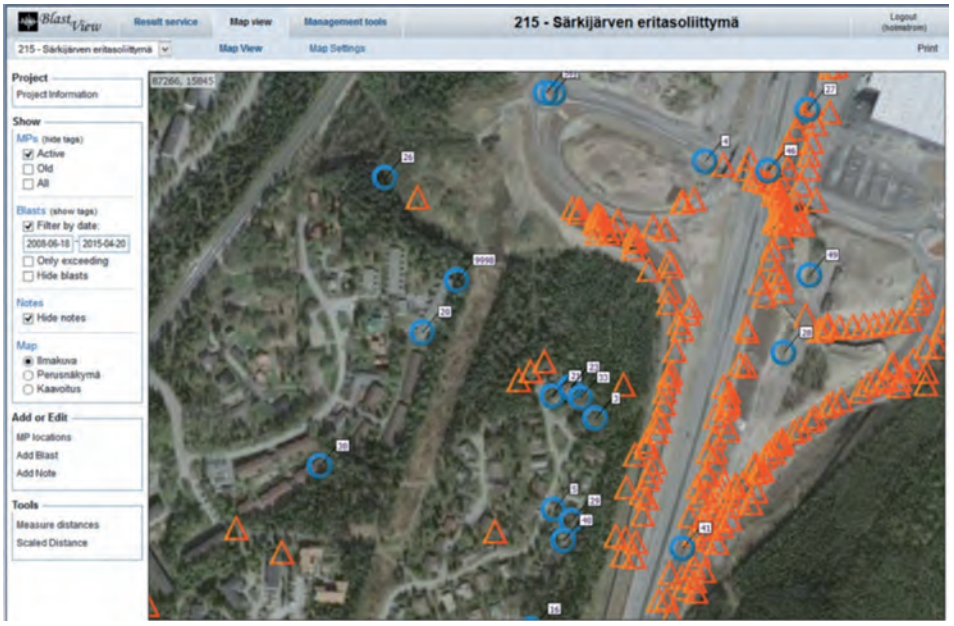

Figure 9 : An example of a BlastView map view. Maybe several tools not to advertise any specific system.

5 >> Using the vibration data for optimization

Systematic use of vibration measurement data as a feedback can be utilized as one source of information in D&B optimization. Based on the vibration analysis the charges, detonation control and location of the holes in the plan can be adjusted. To have a control of blasting vibration can mean more tunnel meters per day as shortening the round length or partial tunnel blasting might be avoided.

Vibration measurements systems can warn about overshoots or near-to-overshoot values of the data.

If vibration data is examined against the momentary design (against time-kilos-graph), the correlation between vibration data and the designed hole charge blasting can be found. This will not only express the PPV-value of the round's blasting in that particular measuring point, but the data can be studied in detail as well.

When vibration data amplitude's absolute value is scaled to generally match the blasted kilos, the remaining deviations between these two values can be observed (see Figure 12).

When incoherence is found, typical first steps are quality control of the charging work and detonation system. An overshoot might be due to too big momentary design or wrong detonator or misfire in some of the previous hole(s). It can also be due to too heavy burden with this group of holes.

The holes in question can be pinpointed based on the timing value and this is an indication where the D&B plan editing should be concentrated.

In case of an overshoot or near-to-overshoot, the corrective actions can be:

- tuning the detonator design timing if possible to reduce a hole from this number
- reducing the burden of these hole(s)
- adding some more holes and reducing the charge (kg) of the holes. E.g. specific charge is not changed but specific drilling is increased

Figure 10 : A traffic tunnel heading in Finland. Photo courtesy of City of Tampere. Excavation work done by Lemminkäinen Oy

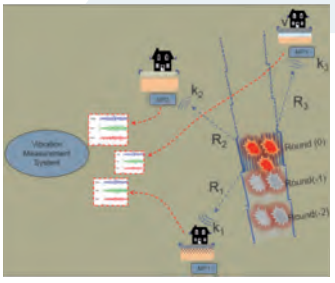

Figure 11 : Advancing of the excavation of the tunnel. Blasting generated vibration is recorded and analysed systematically after each blast from various measuring points.

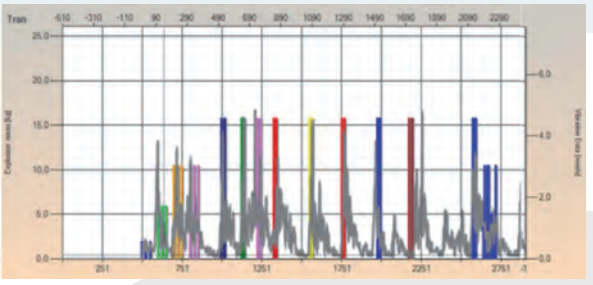

Figure 12 : An example of momentary design and vibration level [mm/s] scaled against each other.

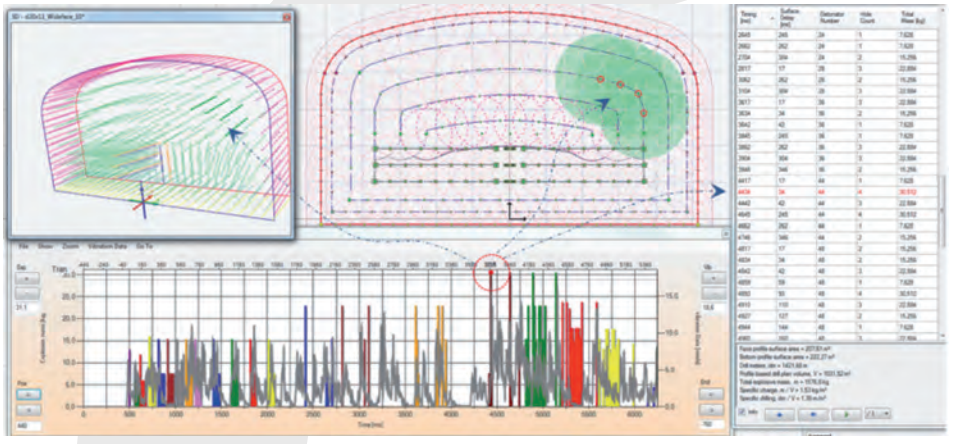

Figure 13 : An example of momentary design and scaled vibration level [mm/s]. Both overshoots and delayed detonation (maybe due to detonator quality or error in connection) can be detected.

5 >> Using the vibration data for optimization

In general, increasing the awareness of blasting generated in detail together with corresponding design, among the tunnelling workgroup acts as a quality control and improvement of the blasting.

Tight vibration limits require a reliable detonation system, good charging and detonation design, accurate drilling (burden and spacing) and proper cut design. The reward of systematic analysis is maximum round length, reasonable amount of drilled holes and avoiding partial face blasting as long as possible. A more predictable vibration of the blast can increase D&B excavation progress.

When charging units develop in recording the amount of the explosives and detonator number during the charging for each hole and this data can also be attached to analysis, it will open even more possibilities.

Some key points to remember:

- Reducing the Maximum Instantaneous Charge (MIC) tends to increase the number of holes required in the face, but smaller hole diameter (~48mm) can be used
- Smaller hole diameter increases typically the partial charge blasting reliability of emulsion explosives
- Smaller charges increase the profile quality (assuming good drill plan, top quality drilling and detonation)
- Smaller charges reduce the blasting damage zone
- Better profile quality can reduce amount of shotcrete required
- Better profile quality reduces scaling time and can increase safety
- Conversely, increasing the number of holes increases the cost (numb of holes and detonators).

6 >> Interface initiative

Main purpose of this document is to declare an initiative for a common interface between vibration measurement systems and D&B design programs. This would help all parties in controlling D&B vibration in a cost-effective way.

The role and data management of vibration measurements systems would be the same, only data from any interesting measuring point could be utilized to assist the actual D&B design. Figure 14 presents the basic data flow idea and 15 presents the format initiative.

An xml- format was chosen to be easy to read and implement.

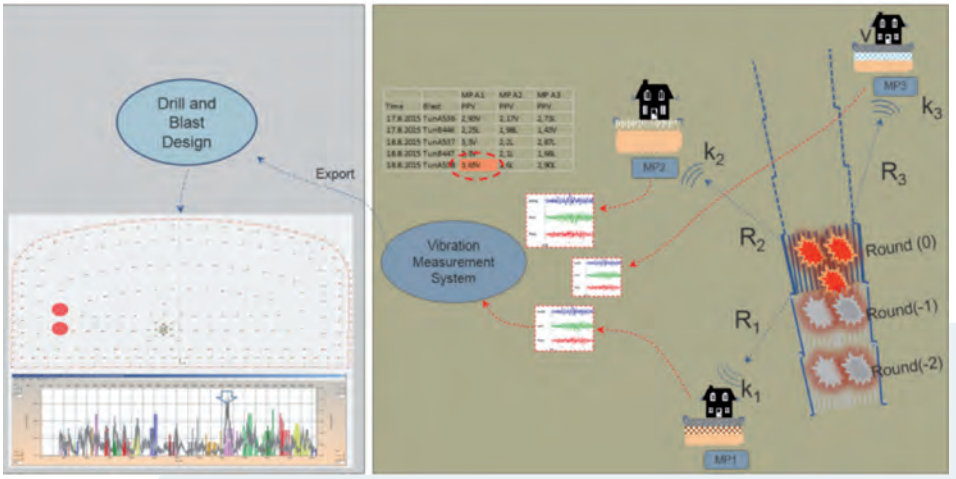

Figure 14 : Utilizing vibration data from an interesting measuring point.

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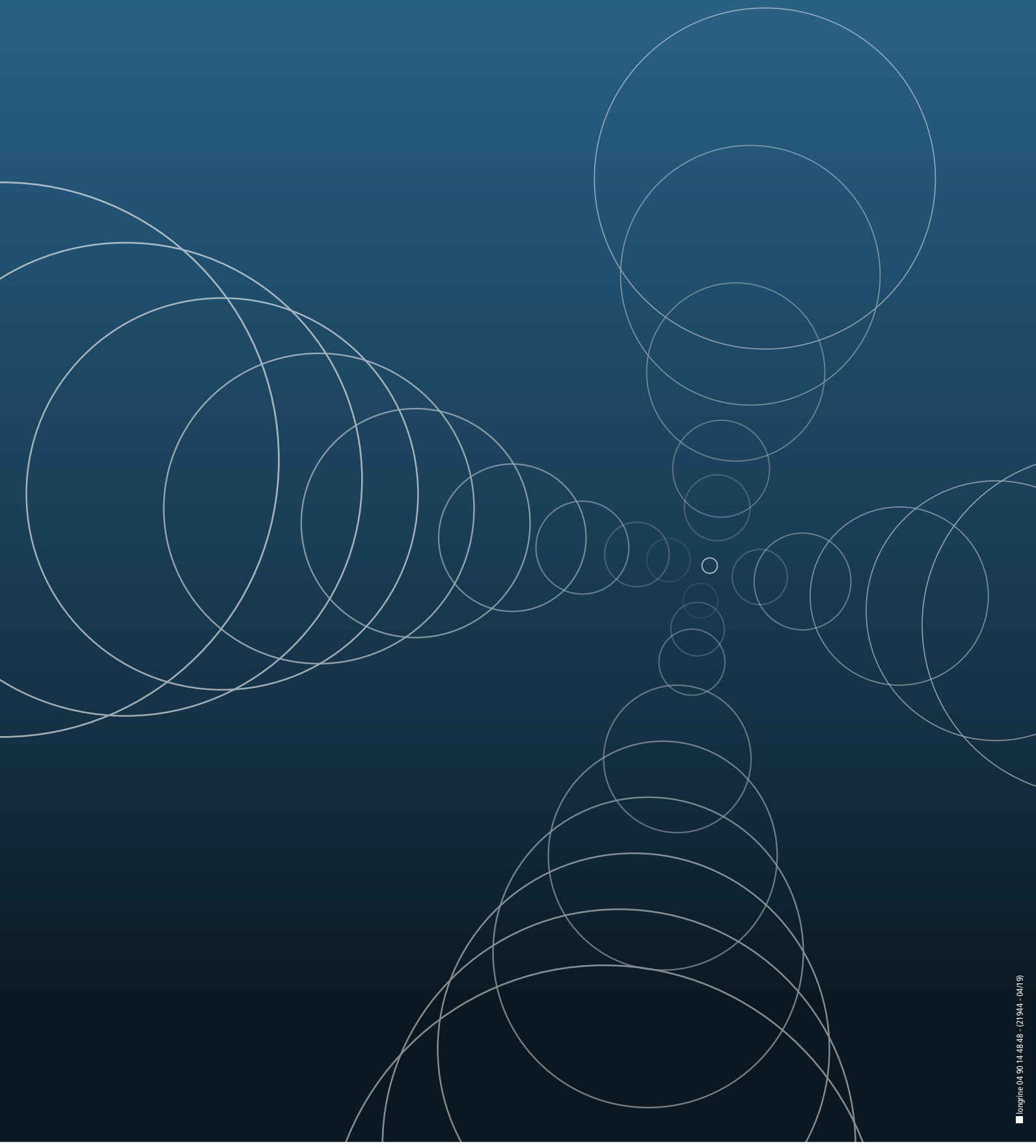
Figure 15 : An 0.0.1 version of an xml-format vibration data file for discussion. In picture the start of the file (a header) describes time and location among other, then comes in the measured values in 3 axis directions (continues like that) and lastly closing down xml-tags.



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