VIBRATIONS MONITORING IN LARGE CIVIL STRUCTURES

THE VERNAGO’S DAM CASE

ABSTRACT

Vibrations monitoring of large structures during construction works requires an appropriate know-how, as well as high functional features of the measuring equipment. Whenever a vibrations monitoring system comprising many sensors locations over a large area should be deployed, several questions arise.

How do I install the sensors providing local power supply? How do I easily retrieve data from each sensor? How do I grant simultaneous data acquisition? How do I avoid EMC noise in cables?

Sequoia IT, with the GEA SYSTEM, has been able to provide the right answers for the above problems. The advanced, cost effective, technical solution based on a network of distributed digital sensors demonstrates to answer in most effective way to the requirements of large monitoring system if compared with traditional solution.

The company GDTest had the need to provide a continuous monitoring of the vibrations produced by excavation work for the construction of the new diversion tunnel of the Vernago’s dam hydroelectric plant.

It was necessary to provide a system managed by two independent dynamic units with the ability to connect a certain number of sensors to the two units, as required and depending on the progress of work.

A total of 16 tri-axial sensors have been used, able to perform a continuous monitoring of 6 months and to ensure the remote control of the instruments, in order to send data to the server.

An application of the GEA System, regarding the monitoring of the vibrations induced by the construction of the diversion tunnel of the Vernago’s dam hydroelectric plant, is shown here.
WHY TO MEASURE VIBRATIONS

Vibrations are caused by various activities in work sites:

- Heavy Duty Machines
- TBM (tunneling)
- Blasting

And can generate both structural damage and human discomfort in the surrounding buildings or in the structures under construction itself.

WHAT TO MEASURE

When a mechanical system vibrates, it has an oscillation around an equilibrium point.

We have three interrelated parameters that we can measure:

\[ D = \text{Displacement} \]
\[ V = \text{Velocity} = \frac{dD}{dT} \]
\[ A = \text{Acceleration} = \frac{dV}{dT} = \frac{d^2V}{dT^2} \]

In civil application is usual to measure the Vibration Velocity since it is directly correlated with the energy “supplied” source of the possible structural damage.

\[ E = \frac{1}{2} m V^2 \]

Mainly the Peak Value is measured.

It is not enough to evaluate the peaks value because phenomena having an equal peak levels have a different effects depending on the frequency.

LIMITS OF ACCEPTABILITY

In Buildings, PCPV/PPV values are compared with reference standard curves.

Those curves are different for any country, but are based upon the same criteria:

- Type and usage of the building
- Type of vibration signal
- Frequency content of the vibration signal

As a rule of thumb:

- Historical buildings are more sensitive to vibration
- Impulsive vibrations, such as those caused by blasting activity, are less damaging than continuous vibration induced by heavy duty machine.
- Low frequency content is more dangerous than high since signal at low frequency decade in a longer time.

Therefore is necessary to calculate, by means of frequency analysis, for each component (X,Y,Z or Longitudinal, Transverse and Vertical) the PCPV (Peak Component Particle Velocity). It is given by the pair:

Velocity Peak and corresponding Main Frequency

And/or it is possible to determine the PPV (Peak Particle Velocity), which is a pseudo vector given by the 3 peaks components and the frequency of the highest component (DIN 4150 part 3).
For Massive Rock Structures, the BLAST DAMAGE INDICATOR (BDI) is often used.

\[
BDI = \frac{\text{Induced Stresses}}{\text{Rock Tensile Strength}}
\]

\[
\text{Induced Stress} = PPV \cdot \rho \cdot c
\]

\[
\text{Tensile Strength} = T_d \cdot K_s \cdot 10^6
\]

According to the BDI it is possible to evaluate the Damage Type:

<table>
<thead>
<tr>
<th>BDI</th>
<th>Damage Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.125</td>
<td>No damage</td>
</tr>
<tr>
<td>0.25</td>
<td>No Damage</td>
</tr>
<tr>
<td>0.50</td>
<td>Minimum chip off (scabbing), not extended</td>
</tr>
<tr>
<td>0.75</td>
<td>Moderate and Discontinuous chip off effects</td>
</tr>
<tr>
<td>1.00</td>
<td>Large and extensive effects of scabbing</td>
</tr>
<tr>
<td>1.5</td>
<td>Serious damage on free surfaces</td>
</tr>
<tr>
<td>&gt; 2.00</td>
<td>Risk of extended collapses</td>
</tr>
</tbody>
</table>

The reading of the continuous component allows:
- Calibration verification with the only reading of gravity
- Self-levelling

Moreover:
- Can be directly fixed to the wall without the need for additional mounting accessories
- Grade of protection: IP68 – can be put under water

The system can count on dedicated software GEA-Lab:

- Suitable for both evaluation of structural damage and comfort (at the same time)
- Large selection of standards (new can be easily integrated)
- Suitable for both short measurement and for long term and permanent monitoring
- System event notifications via email (remote) and through local relay
- User friendly
- Simultaneous management of multiple sensors

In addition, a Report tool data has been developed.

GEA ensures a digital data transmission without EMC disturb even over long distances with very long and low cost cables (up to 1 km).

For long monitoring measurements, to connect far measurement points to a single unit and/or when it is necessary to leave the system in measurement sites. A dedicated Monitoring Box has been developed, that ensure you:

- Modular system up to 16 sensors
- Optional modules for remote connection (GPRS)
- Optional modules for local alarm (relay)
- Processing units pre-configured with the Linux operating system for greater stability on the long monitoring

GENERAL REQUIREMENTS

WHY TO CHOOSE GEA SYSTEM

Before choosing a system, it is important to understand what are the real needs as well as the advantages to be gained from choosing it.

GEA System is composed on a digital triaxial sensor, based on MEMS technology with low ground noise. MEMS are robust, maintenance-free contrary to the classical geophones and Linear response from DC at 1000 Hz (typically, the classic Geophones have a resonant frequency around 4.5 Hz and therefore it is necessary to linearize).

The Sync-Hub, supplied with GEA, is a simple and cost-effective device that ensures:

- Power of 4 sensors, up to 1km away, simply through the USB port of the PC
- Perfect match phase (sync time) among 4 sensors connected
- Connectable in chain with three other modules for a total of 16 sensors (standard system)
MONITORING ON DIVERSION TUNNEL BUILDING

The work involved the excavation of the diversion tunnel performed by blasting and roadheader machines.

“In your product is perfectly suited to our measurement needs, with the great advantage that the sensors do not require a specific electricity supply at the “point of installation, but they are supplied directly from the signal cable”

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controlled remotely and providing email-alert in case of exceeding pre-established thresholds, was necessary to employ.

In particular, even though the customer was used alternative traditional systems, he preferred to use GEA System.

Why? Because the GEA has been able to provide the Added Value that the customer was looking for.

In a nutshell, synchronized sensors, located along the tunnel, totally submerged by water, capable of being

In detail, the GEA System solution, has met the requirements, as it ensures:

✓ measuring points also 2 km away from each other
✓ using cables that transmit the digital signal to the central unit. In fact, the unit performs a synchronization between the different sensors
✓ having sensors that do not require a specific electricity supply at the point of installation, but are supplied directly from the signal cable
✓ possibility of monitoring areas where the GPS signal is not available
✓ watertight sensors to monitor immersed points

“A satellite photo showing where the GEA Systems have been placed. Two systems, which have worked for a continuous monitoring of 6 months, have been composed by a total of 16 sensors (6 on a system and 10 on second one, for a total of 6 km of cable connection).

“The decision to buy your product has matured even after a market inner extensive research that has favored your product, focusing on the ratio features / cost compared to alternatives that meet the technical specifications of the tender notice”

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