GURALP SYSTEMS

Case study

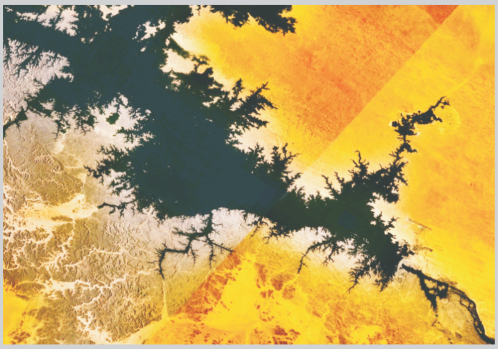
Strong-motion instruments for dams

Modern large dam projects often include strong-motion seismic arrays, which can be built in to the dam at the time of construction. Seismic data is benefical to the project, since it provides

- accurate data on local seismic activity, including any changes caused by the construction of the dam;
- a way of verifying the design parameters of the dam as constructed;
- information on the dynamic behaviour of the dam, which can be monitored for signs of structural damage or deterioration, or analysed after an earthquake.

In addition to this, the arrays provide general seismic data for defining earthquake parameters, mechanisms and frequency characteristics. The most advanced arrays use both weak- and strong motion instruments to measure smaller vibrations as well as major events. Because arrays on dams are spread throughout the structure, data flow and processing is a central challenge. [Mihailov and Dojcinovski, 2001]

These arrays provide significant contributions to our knowledge of dam behaviour, allowing engineers to refine designs towards the goal of minimal seismic response. Nevertheless, the number of dams incorporating instrument arrays is still relatively small.



Güralp Systems' accelerometers provide a truly cost-effective way to build dense strong-motion broadband arrays. Combinining these with our flexible digital hardware and telemetry systems, engineers and scientists now have access to a wider range of instrumentation options than has previously been possible.

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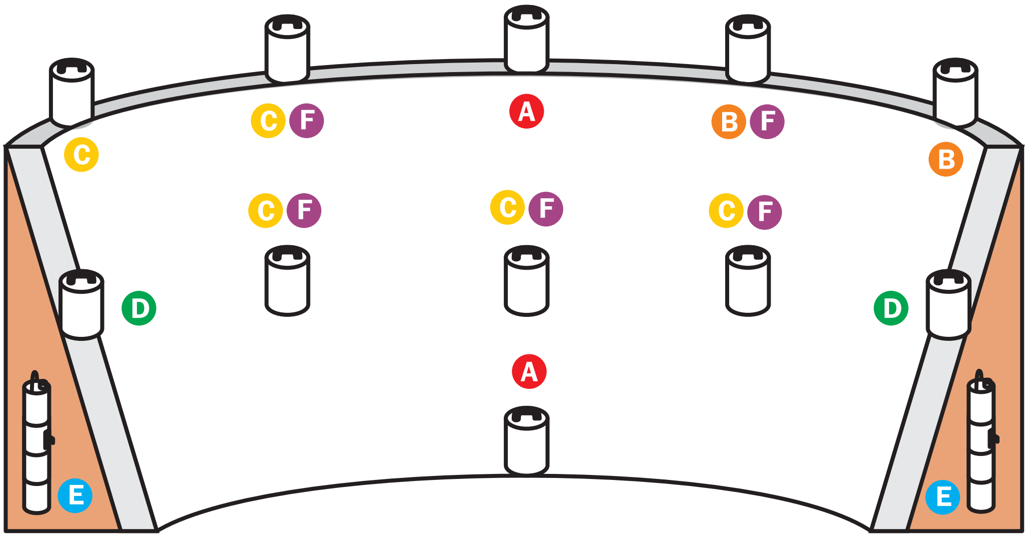
Array design

The locations of instruments around a dam should be carefully chosen to maximise effectiveness. [Darbre, 2001] Consider a typical arch dam:



Three particularly important sets of measurements can be identified:

Dynamic response: Dams, like any structure, have vibrational modes which can be excited by ground motion. To measure these, instruments need to be placed near the points of maximum modal deflection, at positions A (for a minimal installation) and B. For more detail, especially on a non-symmetrical dam, instruments may be added at positions C.

Effective input motion: The interface between the dam and the ground is complex and often inadequately studied. To determine the effective input motion, instruments need to be placed along the interface (positions D), and possibly in foundation galleries (positions E).

The free field: Finally, the natural ground motion in the region needs to be monitored, both as a reference for the above two quantities, and to study the effects of the dam and reservoir on local seismicity. Instruments in the free field need to be close enough to the dam to be representative of the ground motions there, but far enough away that the dam itself has little effect.

As a real-world example, the Pacoima dam in California combines triaxial instruments at positions A and D with uniaxial (radial) sensors at F. Studies following an earthquake in 1994 showed this design to be effective, although the lack of a free field reference was considered a weakness. [Fenves, 1997]

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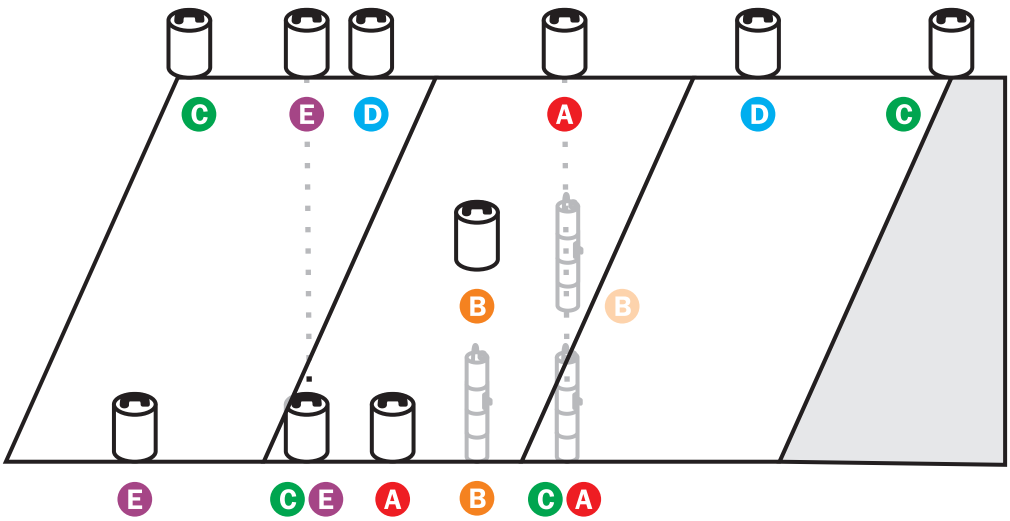
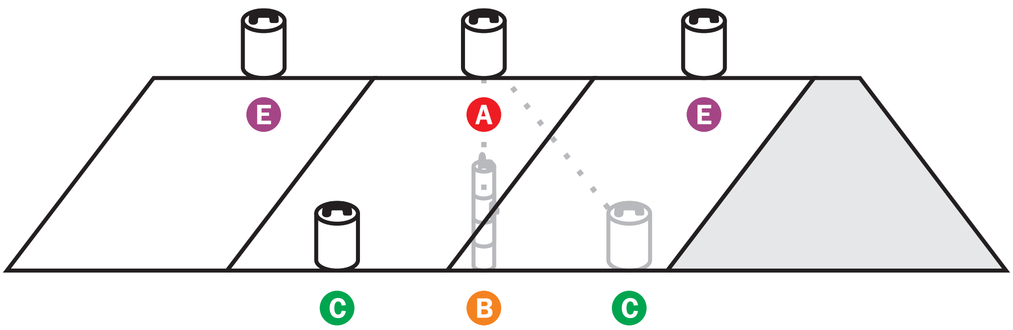
Gravity and embankment dams

A gravity dam is made up of a number of identical monoliths, which may be treated as moving independently. [Darbre, 2001] The variation of effective input motion across the base is a major factor.



Dynamic response: Positions A; B for more detailed results. Instruments within the dam can be placed in boreholes (for earth dams) or galleries.
Tridimensional response: Positions D, instruments placed at ¼ points.
Effective input motion: Positions C, instruments placed at the base of monoliths and at each side of the canyon.
Behaviour of independent monoliths: Positions E, instruments placed on each monolith as required.

Embankment dams can also be considered as independent monoliths, so if bidimensional response is assumed, designers can apply the same basic scheme as for gravity dams.



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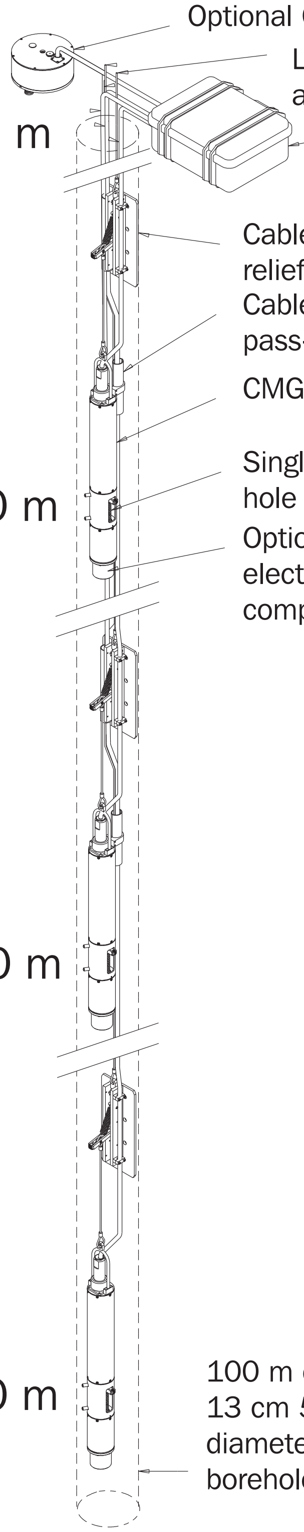
Strong motion boreholes



As for all our standard instruments, the CMG-5T is available in both surface and borehole forms.

The borehole CMG-5TB is well suited to exploring behaviour within dams, and around the soil-foundation interface: an important region which has to date received little attention.

Where dams are built on a soil foundation, or where soil is the major component of their construction (as in most embankment dams), borehole instruments provide the best way to detect deformation and slippage in the soil layers. This information is of vital importance when assessing potential earthquake impact, since the greater part of the damage caused by many earthquakes can be traced to amplification effects in the underlying soils at certain frequencies. [R. D. Borcherdt *et al.*, 2001]

Pass-through systems are available which allow instruments to be located at different depths within the same borehole, greatly reducing construction costs. Up to 4 surface and borehole instruments can be connected to a single 12-channel DM24 digitizer.

The CMG-5TB can be colocated with a CMG-6TB medium-motion instrument, providing scope for more detailed study of ambient vibrations and the dam's response under normal loading. The CMG-6TB is capable of operating at up to 8 ° of tilt.

The exact orientation of the sensor can be determined using an optional built-in electronic compass.

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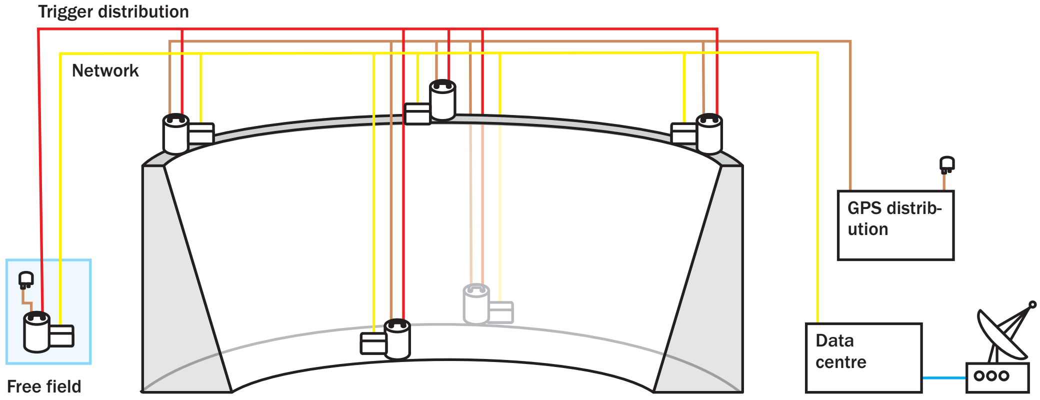
Event detection and triggering

Strong-motion projects often use triggering systems to identify and record seismic events for analysis.



A digital sensor (such as the Güralp CMG-5TD) can perform **STA/LTA or level triggering** calculations, and output high rate streams when an event occurs. Using a dedicated **external trigger** network, the entire array can be triggered from any of the component sensors, ensuring that full data records are always available.

The CMG-5TD supports up to **8 Gb of Flash memory** for data. It can also transmit it over a **serial network** in real time. These features mean that data can be collected at a single central point for event extraction and analysis, or for injecting into network triggering systems (used in safety monitoring applications and early warning systems.) The serial link is also used for **remote firmware updates.**

With the improvements in sensitivity of instruments in recent years, engineers have been able to begin investigating the behaviour of dams and other structures under ambient seismic conditions. [Ivanović et al., 2000] Güralp Systems' accelerometers are ideal for these studies, with a **dynamic range over 140 dB** at long period. Velocity sensors such as the CMG-6T, also available in borehole form, can be added for even greater resolution.

Combining these two approaches, events are increasingly being studied in context as part of a continuous seismic record. Scientists and engineers are beginning to share strong motion data from a wide range of networks, combining our knowledge of earthquake mechanisms with detailed analyses of their effects on large structures.

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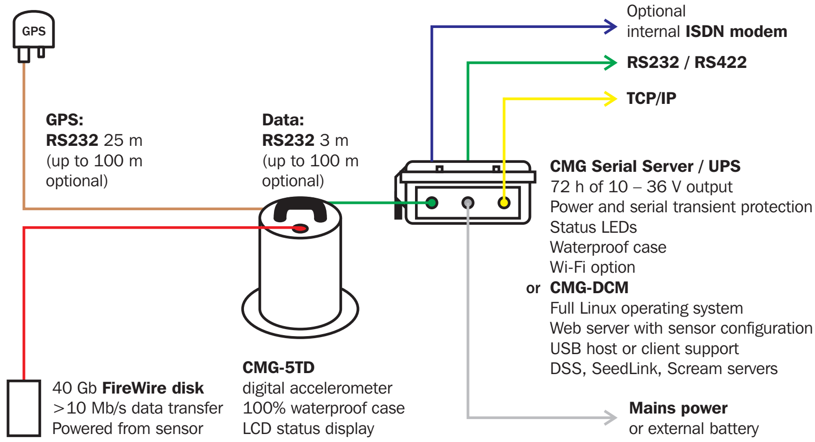
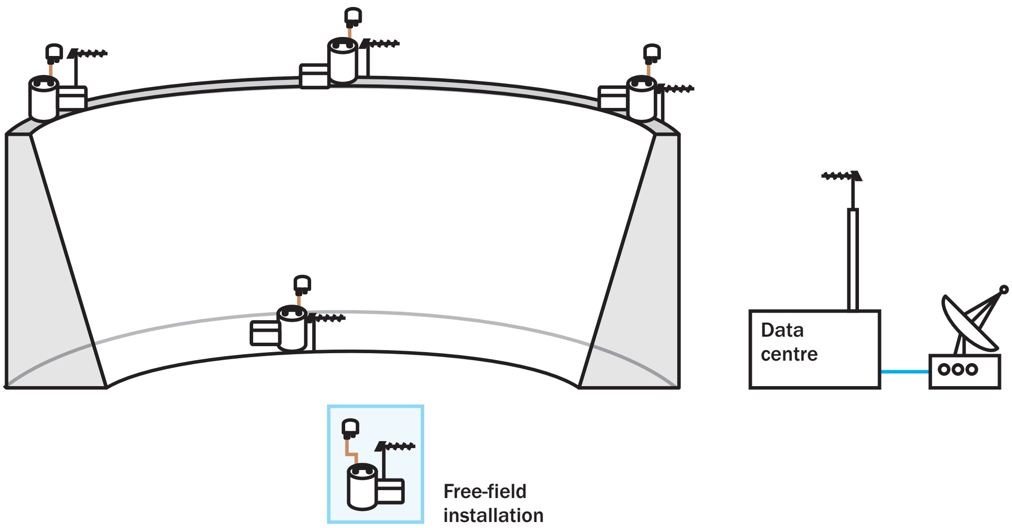
Data flow and networking

As we have seen, a modern digital installation is capable of collecting data and identifying events automatically, greatly simplifying the process of analysis. [Mihailov and Dojcinovski, 2001]

Güralp Systems hardware works as a modular system using standard protocols, giving engineers the flexibility to design the network to their needs. A single installation might use any of a wide range of technologies:



Stations using any of these options can be combined to form the full array. Where arrays are installed during dam construction, a **local area network** is often installed as part of the basic infrastructure. Alternatively, **RS232, RS422, fibre-optic, Wi-Fi (802.11b) or radio links** can be used. Wireless technology is particularly attractive where laying dedicated cabling would be impractical, or for temporary experiments.



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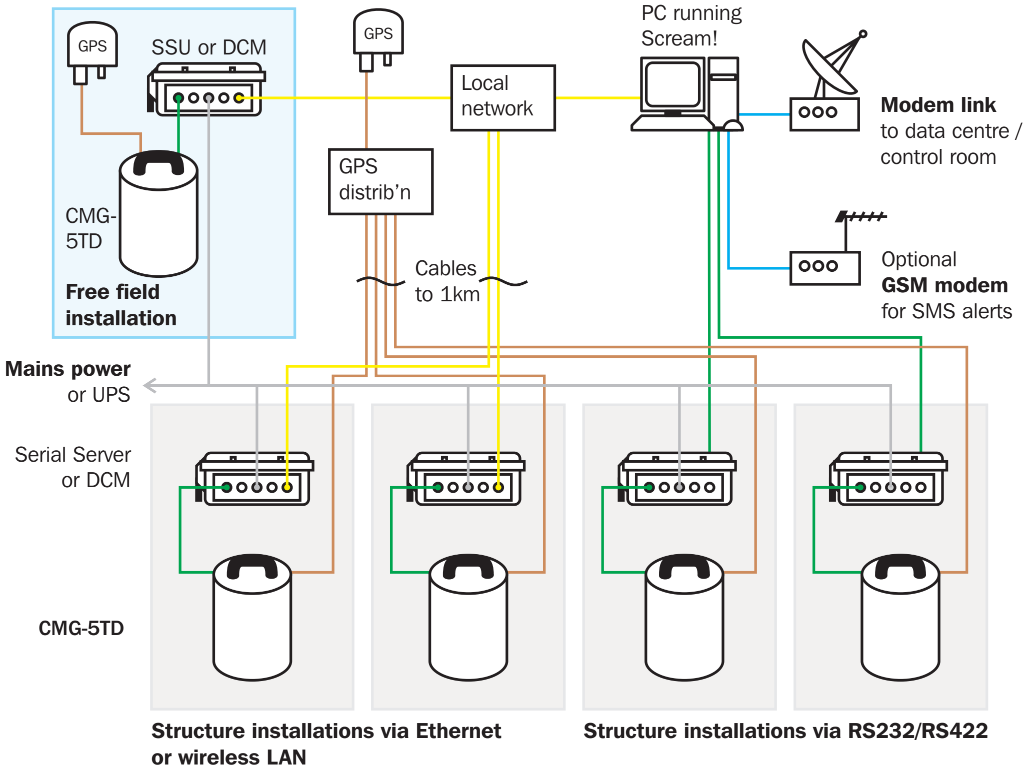
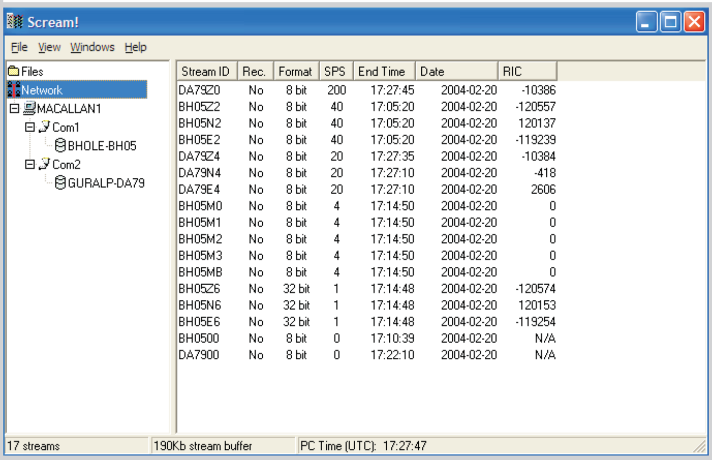
Data flow and networking

Installations connected by RS232 and wired or wireless network links can be combined in a single array as required.



A PC running Güralp Systems' **Scream! software** can collect data from any number of sources and archive it to a local hard disk, or retransmit to a data centre further afield. Scream! can **convert data** into a number of common formats, including MiniSEED and UFF.



Using Scream!, operators can also **configure and control** Güralp digitizers remotely.

When a low-power solution is required, the **Linux-based CMG-DCM** can also combine streams from multiple installations and transmit over a modem link to your data centre. Configuration and control can be performed using the DCM's secure Web server.

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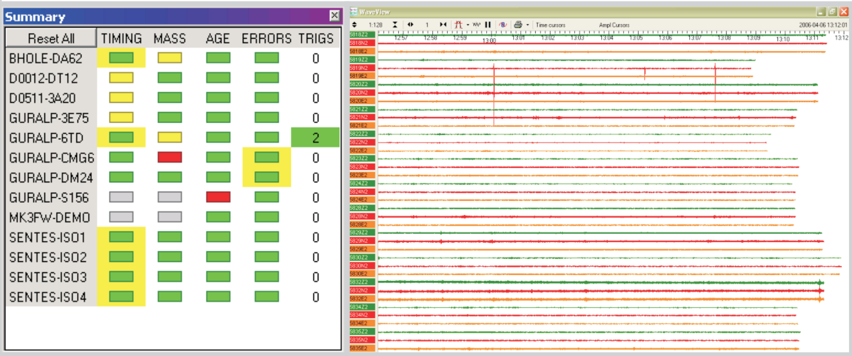
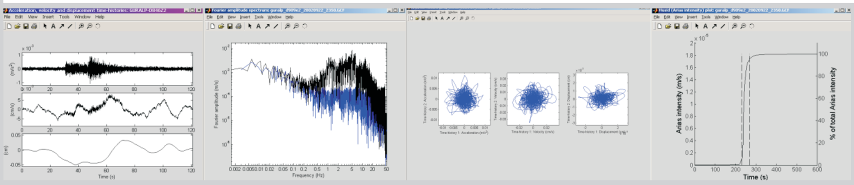
Monitoring and analysis

Scream! includes a range of monitoring features for seismic networks. As well as displaying real-time data from any number of instruments side by side, Scream! provides at-a-glance timing, mass position and data integrity information for monitoring purposes, and identifies triggers when they occur. Archived data can also be replayed through Scream!.

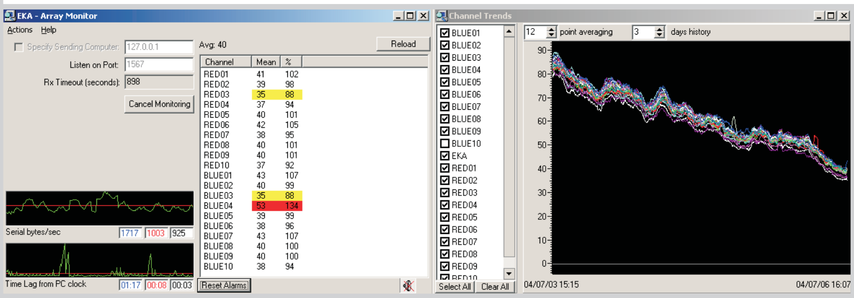


Standard **extensions to Scream!** allow operators to generate instant PSD plots, and interpret calibration experiments.

Güralp Systems' strong-motion analysis tool, **ART**, extends Scream! still further. ART offers a wide range of commonly-used analysis techniques, including uncorrected and corrected response spectra, particle motion analysis, spectral intensity and Arias intensity plots.



Completing the suite of analysis and monitoring software, ArrayMon focuses on the **seismic network** as a whole. Developed for use at existing arrays operated by Güralp Systems, ArrayMon provides operators with constantly updated information on **state of health, instrument outputs and channel trends.**



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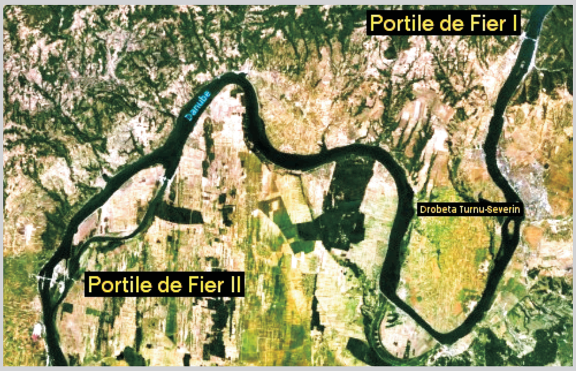
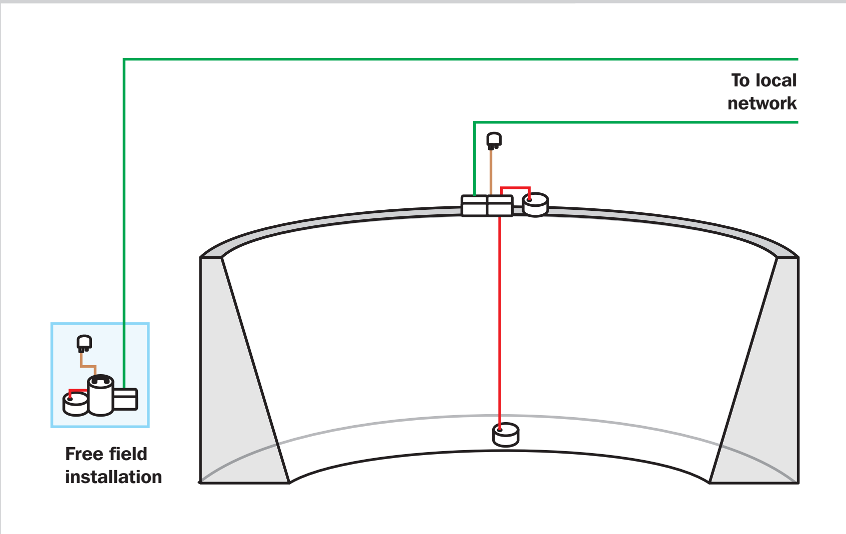
Case study: Portile de Fier, Romania



The Portile de Fier hydroelectric complex is located on the River Danube, where the river leaves the gorge of Portile de Fier ("Iron Gates"). At this point, the river forms the boundary between Romania and Serbia.

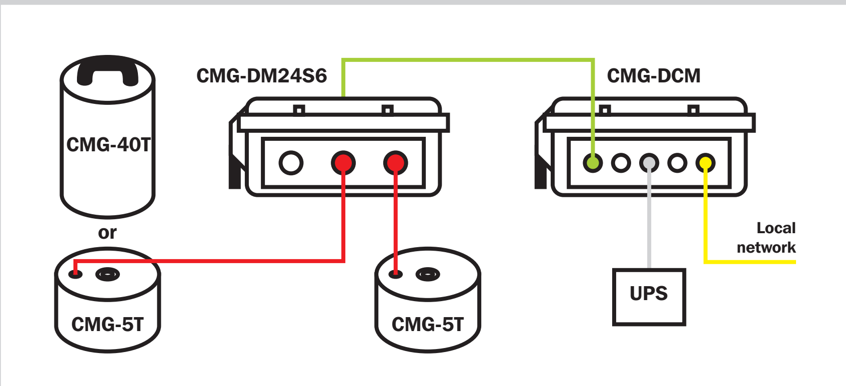
Constructed between 1964 and 1972, the Portile de Fier I dam was the first to be constructed across the Danube, and created a reservoir stretching through the gorge as far as Belgrade.



In 1984, with the completion of a second dam 80 km downriver of the first, the hydroelectric complex reached its current configuration.

Hidroelectrica, the state-owned operator of the Romanian project, commissioned an array of 8 Güralp instruments to study the movement of the dam and monitor its structure.

The array is spread over four sites.



At two of these sites, two CMG-5T strong motion accelerometers are installed on each dam.

They are connected to a 6-channel CMG-DM24 digitizer and CMG-DCM data communications module.

The CMG-DCM interfaces with the local network (installed as part of the dam infrastructure) over a fibre-optic link. Power to the installations is provided by an on-site UPS.

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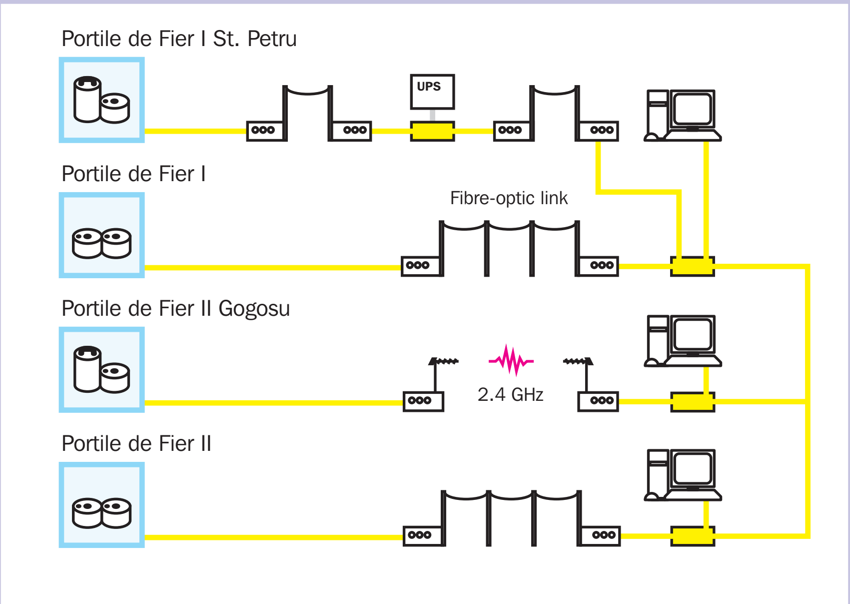

A further installation at St. Petru, near Portile de Fier I, contains a CMG-5T instrument and a CMG-40T-1 medium motion velocity sensor, with a DM24 and DCM configured similarly to the dam installations.

These instruments measure free-field ground motion, which can be compared with the results from the dam structure during analysis. A fibre-optic link connects this installation to the local network.

The final installation, situated near Portile de Fier II, uses the same hardware as the one at St. Petru. It is connected to the local network over a 500 m radio link at 2.4 GHz.

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G. F. Darbre, *"Instrumentation of dam structures in Switzerland"*, in M. Erdik, M. Celebi, V. Mihailov, N. Apaydın., eds. *"Strong motion instrumentation for civil engineering structures"*, NATO ARW on Instrumentation for Civil Engineering Structures (1999, Istanbul), Kluwer Academic, Dordrecht / London, 2001, 195.

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