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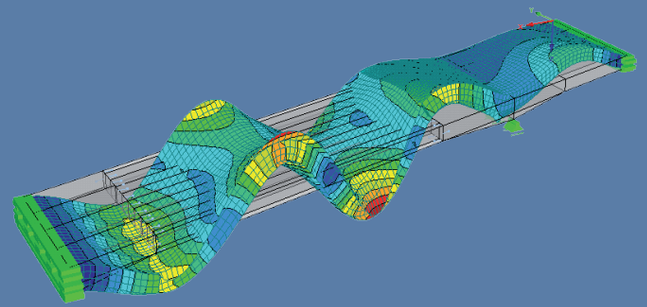
BRIMOS®

Bridge Monitoring System

Dynamic System Identification
and Damage Detection
in Bridge Structures

Examination and Assessment
of Structures in Practice



BRIMOS® – Bridge Monitoring System

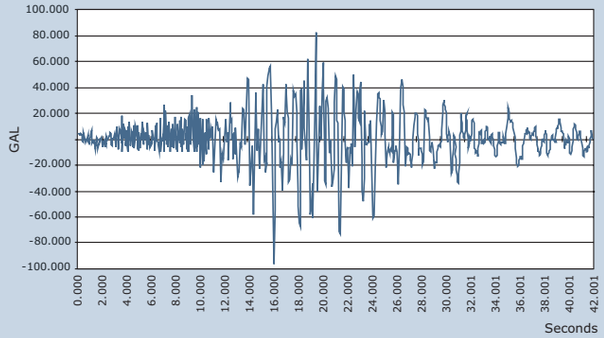
“from vibration to information”

BRIMOS®
Bridge Monitoring System

Ambient Vibration Monitoring can be defined as a method for system identification and damage detection in bridge structures due to its dynamic response to ambient excitation such as wind, traffic and micro seismic activity, The BRIMOS® technology is based on Ambient Vibration Monitoring and has been used for many years in the field of Structural Health Monitoring.

The term Structural Health Monitoring in the mean of Ambient Vibration Monitoring comprises the recording of the dynamic behaviour by the use of measuring instruments as well as the evaluation and analysis of the measured signals. The fundamental tools of health monitoring are system identification – SI, damage determination and localisation as well as safety assessment and the maintenance management for infrastructure.

The measurements are, however, so precise that they can offer reference data with a high qualitative value for every future evaluation method.



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Measurement Technology

Haag, Austria

Nussdorf, Vienna

Brimos-Recorder®

Dynamic, high-precision monitoring

The BRIMOS-Recorder® monitors ambient vibration and allows acquiring knowledge on the current condition of the examined structure very quickly. The vibration signal is measured in three dimensions with high precision and is saved on the internal data loggers for further assessment.

„All-in-one" solution

Our BRIMOS-Recorder® represents an entirely new conception in compact monitoring and assessment equipment.

The main innovation of our development is the design as "all-in-one" equipment containing all required component parts as well as a simplified and very user-friendly operating concept.

Reliable data acquisition

The BRIMOS-Recorder® provides reliable data acquisition of the highest quality. It has the added convenience and flexibility that today's monitoring technology offers. Thus it has a high value for the interpretation by structural engineers.

BRIMOS®-Measurement system

The developed measurement system is the best way to achieve an optimized and exact measurement results.

It exists of:

- → High precision Accelerometers (1-dimensional as well as 3-dimensional)
- → Data logger (µMusycs by IMC) & PC
- → Amplifiers & Filters
- → External Power supply connected with uninterruptible power supply
- → Temperature Sensor
- → GPS
- → Video Camera (infrared, motion detection)
- → Radiation Sensor
- → Optional: Laser displacement Sensor

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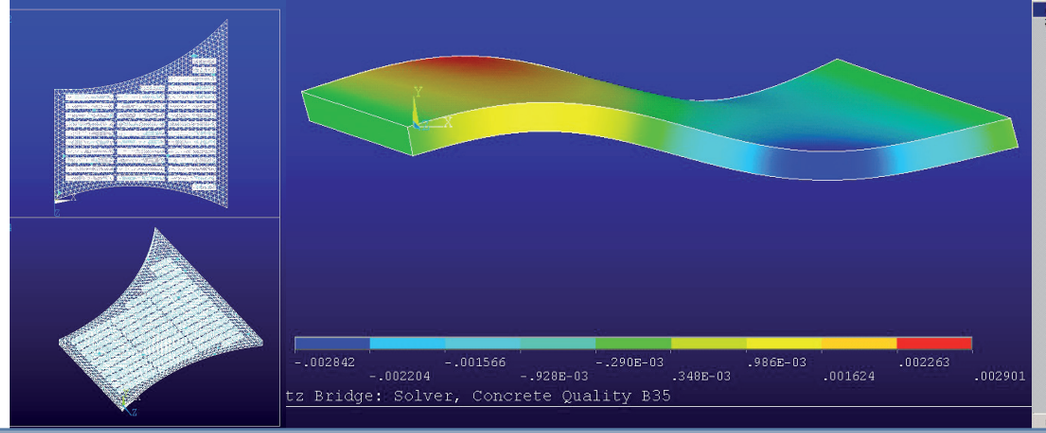
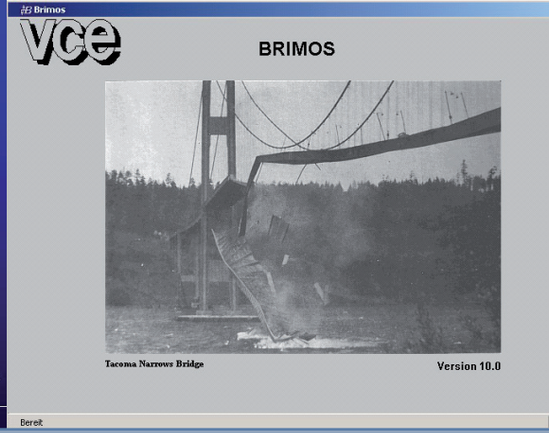


Finite element based dynamic analysis

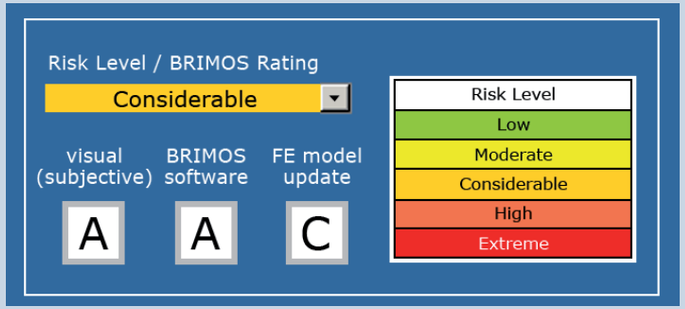


Measurement based system identification

BRIMOS® Classification

BRIMOS® offers a well-defined rating system for investigated structures. This classification allows a fast identification on the structure's integrity as well as the corresponding risk level based on measured dynamic parameters (Eigen-frequencies, Mode Shapes, Damping Pattern in the lengthwise direction, Vibration Intensity and Static as well as Dynamic Vertical Displacements), visual inspection, Finite Element model-up-date and reference data (BRIMOS®-Da-tabase and Brimos®-Knowledgebase).

The result is a 3-letter-determination, which relates to a predefined risk level.



Categories:
→ Category A: good condition
→ Category B: good condition with local damage
→ Category C: problematic condition

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BRIMOS® Measuring


Wind power plant, Germany


Schottwien, Austria


Giuliana Bridge, Libya


Railway Bridge Tulln, Austria

Initial Investigation

Detailed measurements are performed by the means of a compact sensor layout. These measurements allow the identification of the global system (natural frequencies) as well as local behavior (mode shapes, damping) for damage detection and localisation.

The measurement of 200 m of structure per day has resulted as average value for the more detailed basic measurement. A detailed measurement is carried out to establish a comprehensive reference data set of a structure. The modal parameters of detailed measurements can be used for exact system identification and finite element model updating of the structure.

In general detailed measurements are applied for:
→ Condition Assessment
→ Rehabilitation Planning
→ Risk Assessment
→ Quality Control

Periodic Investigation

Monitoring and Verification – the most efficient employment of the system is the execution of measurements in periods with the BRIMOS®-Recorder. Modal parameters from periodic measurements can be used for comparison with results from detailed measurements, design values, analytical or numerical calculations as well as values from the BRIMOS® knowledge base.

The accompanying dynamic examinations at several demolished structures clearly showed that already one sensor, positioned at a favourable spot on the bridge, supplies very high information content with regard to possible damages.

Periodic measurement can be applied for the monitoring of structures and single structural elements such as stay cables, tendons, etc.

In general periodic measurements are applied for:
→ Condition Monitoring
→ Maintenance Scheduling
→ Attendant Monitoring
→ Quality Control

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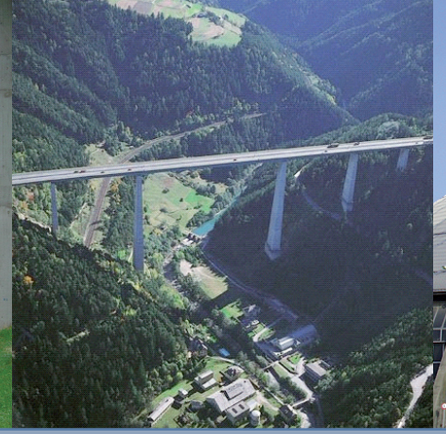
BRIMOS® Measuring


Ško-Energo, Czech Republic


Gschnitztalbrücke, Austria


Europabrücke, Austria


Waste management, Vienna

Permanent Monitoring

For special cases permanent monitoring should be taken into consideration, if there are reasons to doubt the load-bearing capacity or high impact from traffic, wind or seismic activity threatens the structure. For such tasks effective, tailored multi-channel measurement systems are designed and installed which provide information about changed structural parameters. They encourage an advanced decision support for bridge owners in the course of maintaining their infrastructure and are based on structure-specific, objective online information by representing the bridge‘s hot spots.

Permanent monitoring benefits the preparation of statistics on traffic or environmental influences and the investigation of the resulting effects to the structures to trigger warning & alarm levels → alert cases are immediately reported to the headquarters via telemetry.

Knowledge received from permanent monitoring data contributes essentially to the further development of Structural Health Monitoring.

In general permanent measurements are applied for:
→ Condition Monitoring
→ Lifetime Assessment
→ Traffic Analysis
→ Environmental influences

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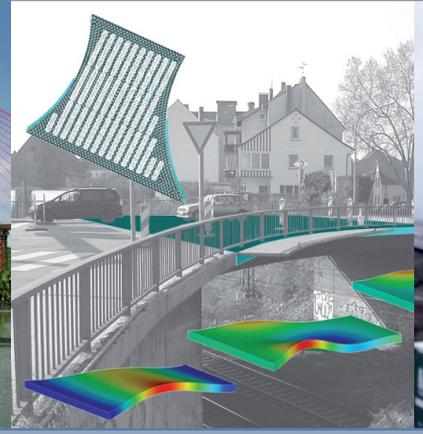
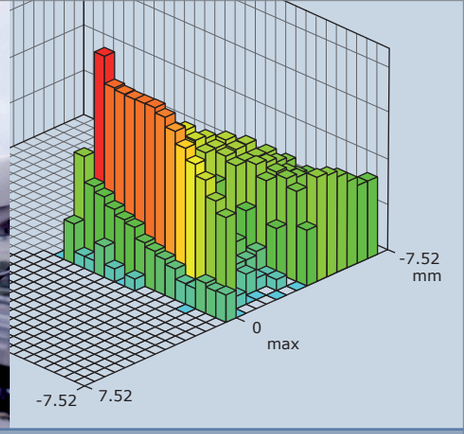
Lifecycle Management

Kao Ping Hsi, Taiwan



Neusatzbrücke, Germany

St. Marx, Vienna



Rainflow-counting

Quality Control

BRIMOS® Quality Control is based on Ambient Vibration Monitoring to check the actual dynamic behaviour of a structure. In other words the measured modal parameters of a physical model (structure) are compared to the determined values from design (analytical or numerical model).

Quality Control is applied during or right after construction or rehabilitation to verify the construction works and services. Especially the cantilever method in bridge engineering, where every construction phase is characterized by new load cases, Quality Control is reasonable to be done in every phase.

Another application of Quality Control is after a construction is finished. This dynamic analysis ensures that an erected structure satisfies the design and that every element, especially support systems, work properly. Many owner and operators already request a dynamic analysis by contract before the hand over of the structure.

Examples of Quality Control:
→ During construction of the Kao Ping Hsi bridge, Taiwan
→ During rehabilitation of the Donnergraben bridge, Austria

Traffic Analysis

An ongoing increase of traffic volume and higher cruising speeds result in a redefinition of dynamic loads to bridges and affects the service life of structures. For this reason Traffic Analyses are often implemented in combination to Lifetime Assessment.

BRIMOS® Traffic Analysis systems measure the dynamic load introduced to the superstructure. As bridges have distinctive dynamic response and represent a bottleneck in the infrastructure they are predestined spots for Traffic Analysis.

The BRIMOS® Traffic Analysis system does not require any construction work and traffic is not affected at any time.

Currently VCE is involved in national research projects regarding Traffic Analysis and Infrastructure telematics. For research reason Traffic Analysis systems are often equipped with video monitoring additionally.

Examples of Traffic Analysis:
→ Flyover St. Marx, Austria
→ Europabrücke, Austria

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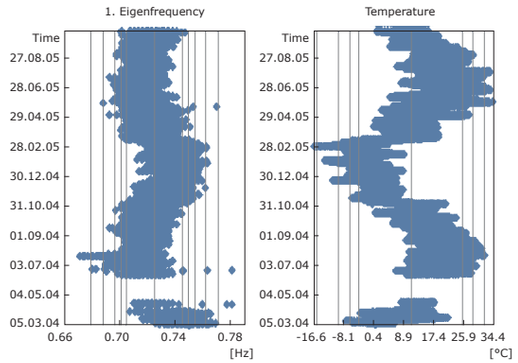
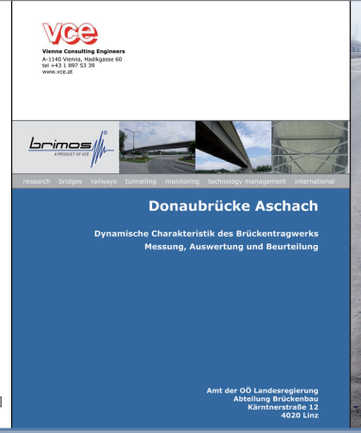
Lifecycle Management



Dynamic stiffness vs. temperature



BRIMOS®-Report

Komořany bridge, Czech Republic

Gschnitztalbrücke, Austria

Condition Assessment

Life-cycle management can be understood as an extension of the typical life-cycle cost (LCC) planning process over a structure's life-time. Usually the LCC planning is completed within the design phase of structures without considering the actual structural conditions. Recent revaluation of LCC from existing civil structures reveals an extensive deviation of the planned maintenance actions and the actual necessity which confirm the opinion that proper Life-Cycle Management of long-term buildings requires an ongoing Condition Assessment process. BRIMOS® Condition Assessments comprises a detailed measurement, system identification for detection and localisation of damages and an expert report explaining the current condition of a structure.

Condition Assessment meets the interests of competent authorities and owners of structures in:

→ Economical inspection
→ Reliable structural assessment
→ Expert reports to assign priorities
→ Savings due well timed and focused rehabilitation work

Examples of Condition Assessment:

→ VOEST Bridge, Linz
→ Industrial smokestack Ško-Energo, Czech Republic
→ Archduke Karl memorial, Vienna

Condition Monitoring

Condition Monitoring is the comparison of the current dynamic parameters from periodic or permanent measurements with reference data from earlier Ambient Vibration Measurements. In many cases Condition Monitoring is applied after BRIMOS® Condition Assessment was done based on a detailed measurement.

Periodic measurements for Condition Monitoring can also be performed by the competent authorities or operators. Therefore the BRIMOS®-Recorder was developed which works on the basis of the following criteria:

→ A sensor at the right location registers damages early and reliably.
→ An easily operable and robust unit is to be aimed at.
→ Sufficient information in measurement data from a few minutes.
→ The files are read by a laptop or PC and sent to VCE by e-mail.
→ The interpretation and representation is carried out by VCE.

Examples of Condition Monitoring:

→ Rosen Bridge, Tulln
→ Taichung Bridge, Taiwan
→ Melk B3a bridge, Austria

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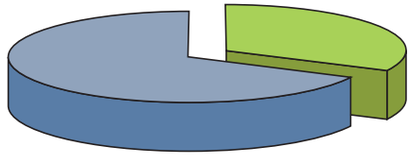


consumed lifetime: 32.2 %

Donaubrücke Krems, Austria

Luegbrücke, Austria

Estakada Bielanski, Poland

Lifecycle Management

Lifetime Assessment

The lifetime of a structure depends on the number of consuming events such as dynamic loads and the resistance which is brought up against this usage. Both are not well defined parameters during the design phase and they are underlying changes during the whole lifetime of a structure.

Long term monitoring (periodically or permanent) of an infrastructure in combination with Traffic Analysis enables Lifetime Assessment based on Ambient Vibration Monitoring.

Reasons for the divergence of the Lifetime defined in the design phase and the actual Lifetime are for example:

- → New rehabilitation methods, better materials
- → Different load conditions (e.g. traffic growth, higher dynamic loads)
- → Quality of building construction
- → Unsteadiness of long-term changes in material properties (e.g. fatigue, relaxation)
- → Short-term changes due local damages
- → Changes in environmental influences

Rehabilitation Planning

Rehabilitation Planning is an additional service offered in combination to the BRIMOS® Condition Assessment and enables well timed and focused maintenance work. Therefore the preceding detailed measurement which is necessary for the Condition Assessment and identification of damages is also used for the establishment of a detailed Rehabilitation Plan. Therefore AVM based Rehabilitation Planning allows highly focused maintenance work.

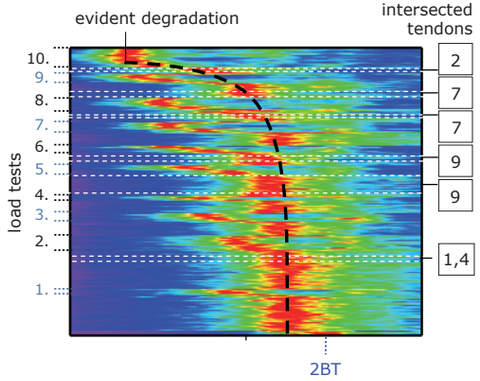
The preceding Condition Assessment avoids the following two kind of bad timed and therefore costly cases:

- → On the one hand damages on the surface initiate expensive rehabilitation measures without being necessary because there is actually no bad structural condition at all.
- → On the other hand the need of repair is recognized at a very advanced stage deterioration which increases the renovation expenses.

Rehabilitation measures recommended on BRIMOS® are classified into:

- → immediate
- → short term
- → medium term and
- → long term actions

Ongoing Research of BRIMOS® – Progressive Damage Tests



Progression of dynamic stiffness

PORR-Brücke, Vienna

Uncovering of prestressing

Cutting of tendons

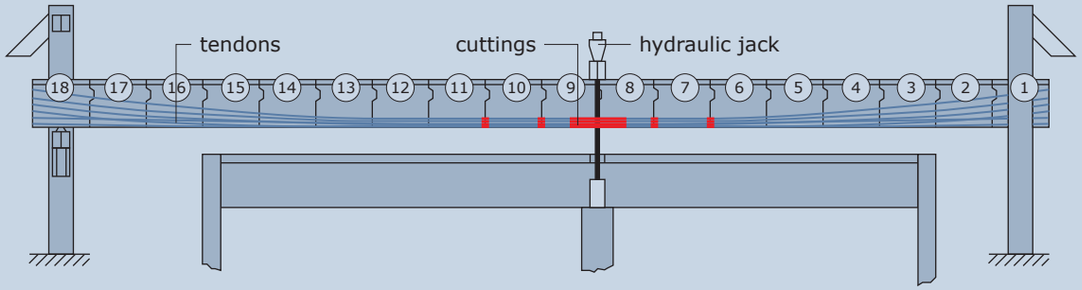
Assessment of dynamic bridge behaviour during progressive damage tests

To verify and optimize the damage assessment tool of BRIMOS® several bridges were artificially damaged in order to determine the effects on the dynamic characteristics.

The progressive damage tests mainly consisted of cutting individual tendons or reinforced bars – supported by destructive load tests – which were accompanied by dynamic measurements.

Based on the dynamic parameters (eigenfrequencies, mode shapes, damping values) the successive impact on the dynamic characteristics caused by the demolition tests was assessed.

So-called trend cards, representing the progression of the dynamic stiffness in terms of eigenfrequencies, as well as the observed damping patterns confirm the applied procedures for the damage identification, localisation and affection on the load-bearing capacity with BRIMOS®.



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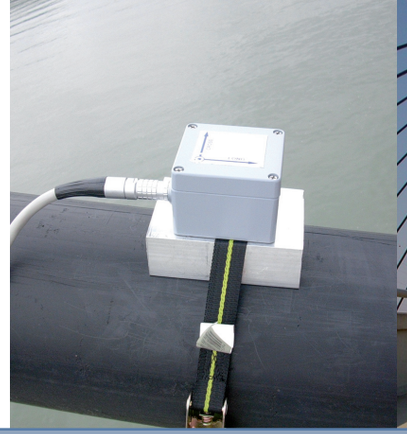
Cable sensor


Rosenbrücke Tulln, Austria


Svinesund, Norway/Sweden


Gersbachtalbrücke, Germany

Cable Force Determination

The increasing number of external pre-stressed elements in modern structures as well as the rehabilitation or reinforcement of existing bridges with this technology raises the question for a technically and economically useful check of effective cable forces or their chronological development. Principally a control of the force with anew application of the pre-stressing jack is possible, but this check is connected with a great logistic, time and therefore also financial expenditure.

Furthermore there is the danger that unintended damages at the cables are caused. For this reason modern, non-destructive procedures are required. Therefore methods such as Ambient Vibration Monitoring are predestined since it enables a quick, flexible and safe determination of the cable force.

The determination of effective cable and tendon forces based on vibration measurement has become a widely known and accepted approach. This means, that there is a proximate correlation between eigenfrequencies and tension forces (comparable to a guitar string, whose tone pitch depends on its tension force).

The exact knowledge of tendon and cable forces is an indispensable requirement during the various construction phases as well as for condition assessment (e.g. cable stayed bridges).

In the framework of several National and European research projects it was demonstrated, that the cable's eigenfrequencies do not only depend on their tension force, but also on their bending stiffness and the supporting conditions of the cable's ends.

VCE's methodology, extracting both decisive parameters – the cable's bending stiffness as well as the so called vibration length – has reached technical maturity.

In the course of numerous projects – completed using BRIMOS® – specific problems concerning cables could be solved.

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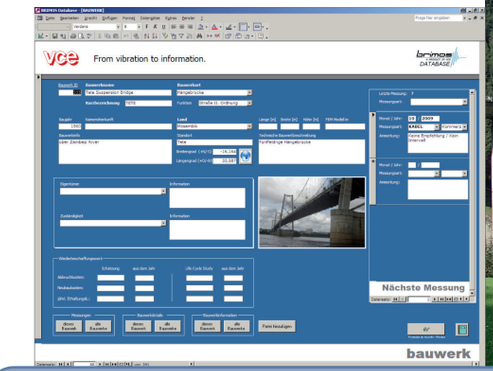
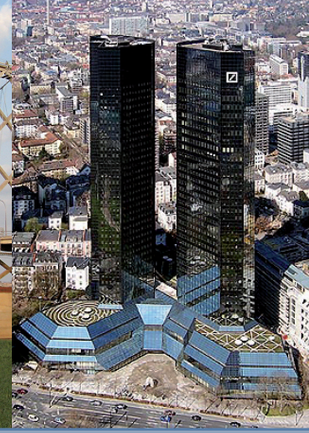


Luegbrücke, Austria

Tete Bridge, Moçambique



Deutsche Bank, Germany

BRIMOS® References

Database

Customer's approval and long-lasting successful application of BRIMOS® made professional data handling necessary. In the first place the integration of the BRIMOS® technology to facility management including GIS requires well defined interfaces as well as organized archival storage. Secondly the technology management is aware about the risk of a slowdown of the evolution on BRIMOS® expertise without a proper data and knowledge base.

The basic concept of the development of the BRIMOS®-Database:

1. Management of data
→ structures (general information, history, condition, maintenance planning, …);
→ measurement data;
→ measurement information (equipment, photos, videos, …);
→ results and expert report;
→ clients.

2. Feasibility to perform queries to gain knowledge from various statistics. The database access for researchers and scientists overarch the arising gap between theoretical know-how and practical verification.

References

BRIMOS® is a development based on several research projects started in 1995. About 1.000 structures worldwide have been assessed and the experience has been incorporated into the assessment procedure.

For further information see:
www.brimos.com