Real-time telemetric monitoring/early warning systems of large engineering constructions with time series linear/nonlinear dynamics processing toolbox

DURATION : 2012 – 2013

TARGET COUNTRIES: Georgia, Morocco, Russia, Turkey, Bulgaria, "The former Yugoslav Republic of Macedonia"

PARTNERS INVOLVED :
Coordinating Centre: GHHD Tbilisi, Georgia
Other centres: ECNTRM Moscow, Russian Federation , ECILS Skopje, FYROM , CEPRIS Rabat, Morocco , ECRP Sofia, Bulgaria
Other partners: AFEM, Ankara, Turkey

OBJECTIVES OF THE PROJECT

Global objective for 2012-2013 :
The safety of large engineering objects (dams, etc.) depends not only on the quality of design and construction but also on the proper maintenance during exploitation and systematic monitoring of construction's condition. Accordingly, development of cost-effective real-time telemetric monitoring/early warning systems of large engineering constructions using network of tiltmeters, strainmeters and other sensors and toolbox of linear/nonlinear dynamics processing methods of monitoring time series for systematic control of construction's stability is the main objective of the project.

Specific yearly objectives :

2012 :
Development of cost-effective scheme of collecting real-time information on time-dependent strains /tilts from sensors and transmitting by Internet to the diagnostic centre and its realization. Testing of real-time telemetric monitoring/early warning systems at Enguri Dam International Test Area (EDITA) using the network of sensors. Distribution of developed technology to cooperating centres and collection of the data on large engineering constructions in their countries, which need monitoring systems. Permanent acquisition of analog signal measurements from sensors (tiltmeters, strainmeters, vibrometers) and finding, whether the latter ones are representative for the main characteristics of construction's mechanical behavior. Creation of long enough data bases of tilts, strains and low-frequency vibrations for linear/nonlinear analysis. Creation and development of the 3d static mathematical model of construction taking into account: geometric parameters; construction material properties, geologic conditions of foundation; operation loads of different origin. Comparative analysis of measured and predicted (by deterministic model-FEM, linear and nonlinear forecasting) data sets in order to derive the main statistical and dynamical features of construction's behavior patterns and to ensure appropriate decision making. Collection of information on selected objects (Large dams) in partner countries and the monitoring systems installed in these objects. Development of plans of cost-effective systems of monitoring automatization and telemetry at selected objects (dams) in partner countries.

2013 :
Compilation of data-base of recordings of sensors (tiltmeters, strainmeters, vibrometers) at EDITA and the selected objects in partner countries for an year 2013. Selection/development of data analysis linear (frequency, time-frequency, singular value decomposition, autocorrelation first zero crossing variation, etc.) and nonlinear (phase space structure, phase trajectory evolution, noise reduction, memory, long range correlation testing, etc.) methods, appropriate for measured tilt, strain, vibration meter data sets during one year load-unload cycle in order to establish construction response to water load. Selection of appropriate to the targeted problem linear (autoregressive) and nonlinear (based on topology of reconstructed attractor) forecasting methods and creation of special diagnostic toolbox for analysis of tilt/strain time series.

EXPECTED RESULTS

2012 :
Design of scheme of collecting real-time information on strains /tilts from sensors and transmitting by Internet to the diagnostic centre. Installation of real-time telemetric monitoring/early warning system at the Enguri Dam International Test Area using the network of tiltmeters and strainmeters and testing its reliability. Data base on monitoring systems in partner countries. Distribution of the scheme to partner centres and testing its applicability to selected objects (dams) in their countries. 3d static mathematical model of construction (Enguri Dam) taking into account: geometric parameters; construction material properties, geologic conditions of foundation; operation loads of different origin.

2013 :
Data-bases of recordings of sensors (tilts, strains) at EDITA and selected objects (Large dams) in partner countries. Processing of these data by the special diagnostic toolkit. Establishment of patterns of time-dependence of tilt and strains at stable state and defining of general signs of closeness to the critical situation for static and dynamic approaches.

RESULTS OBTAINED PREVIOUSLY (if any)

First steps in planning real-time telemetric monitoring/early warning systems of large engineering constructions in Georgia

References

1. M. Bartsh , A. Schiess Zamara, K.Steiger. 2011. Continuous dam monitoring: an essential basisfor reliable back-analysis. The International Journal on Hydropower & Dams. v.18, 51-56.
2. T. Chelidze, T. Matcharashvili, V. Abashidze, M. Kalabegashvili. 2011. Real time telemetric monitoring system of large dams (DAMWATCH): the case of the Enguri Dam International Test area. Proceedings of Symposium "Dams and Reservoirs under Changing Challenges", 29 May-3 June, 2011, Lucerne, Switzerland (electronic version).
3.V. Levtchouk, J. Alberto, E. Gaziev. 2000. Informational support system for diagnosis and prediction of dam's behavior. Geoecology and Computers. Yufin (Ed). Rotterdam, pp.309-314.
4. Automated dam monitoring systems. 2000. Bulletin 118. International Commission on Large Dams. Paris.

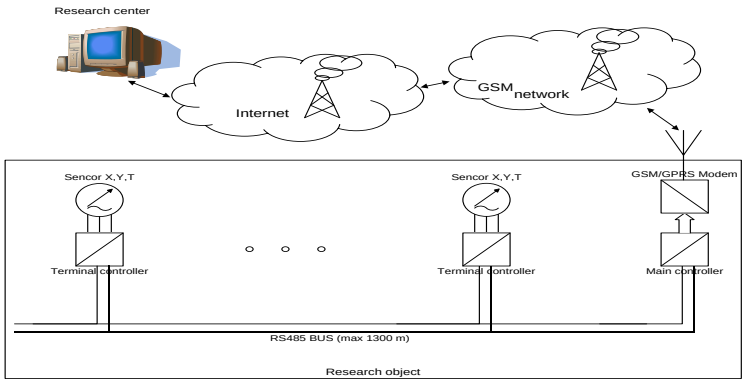
RESULTS OBTAINED IN 2012

Work package 1 (prepared by GHHD):

Description:
Development of cost-effective scheme of collecting real-time information on time-dependent strains /tilts from sensors and transmitting by Internet to the diagnostic centre and its realization. Testing of real-time telemetric monitoring/early warning systems at Enguri Dam International Test Area (EDITA) using the network of sensors. Distribution of developed technology to cooperating centres and collection of the data on large engineering constructions in their countries, which need monitoring. Permanent acquisition of analogue signal measurements from sensors (tiltmeters, strainmeters, vibrometers) and finding, whether the latter ones are representative for the main characteristics of construction's mechanical behaviour. Creation of long enough databases of tilts, strains and low-frequency vibrations for linear/nonlinear analysis.

Cost-effective scheme of telemetric collecting real-time information on time-dependent strains /tilts from sensors and transmitting by Internet to the diagnostic centre and its realization. Testing of real-time telemetric monitoring/early warning systems at Enguri Dam International Test Area (EDITA) using the network of sensors. Distribution of developed technology to cooperating centres and collection of the data on large engineering constructions in their countries, which need monitoring and installed monitoring systems. Permanent acquisition of analogue signal measurements from sensors (tiltmeters, strainmeters, vibrometers) and finding, whether the latter ones are representative for the main characteristics of construction's mechanical behaviour. Creation of long enough data bases of tilts, strains and low-frequency vibrations for linear/nonlinear analysis.

Deliverables:
The created system for large engineering constructions' monitoring data acquisition – DAMWATCH described in detail has been distributed to participating centres 12 October 2012.



The data acquisition system (Fig. 1.1) is a hardware and software suite for collecting data that are acquired by monitoring using sensors located at remote sites for their subsequent processing and analysis in a (research) diagnostic centre. GSM/GPRS and SMS services rendered by all GSM service providers are employed as a communication tools. This is the most cost-effective way of communication for this kind of survey lacking the direct wiring path or access to the Internet.

Basic features of the system

Quantity of the monitoring devices (sensors) linked to the Research Centre:	practically unlimited
Geographical range of separation of monitoring devices:	limited by GSM/GPRS coverage only
Quantity of sensors per object:	30
Maximum distance between the sensors:	1300 m.
Maximum sample rate:	1 sample per minute
Maximum amount of stored data:	262144 bytes

Running time of the master controller in lack of a power line:	48 h.
Running time of the terminal controller in lack of a power line:	48 h.
The cable used as RS485 bus:	UTP CAT5
Necessity of routine service:	not applicable

Requirements imposed to the computer operating as an FTP server at the Research Centre:

- Without any special hardware requirements – any office WINDOWS PC having access to the Internet can be used without any restriction imposed to its basic functionality.
- Explicitly defined LAN IP address.
- Installed Software of the FTP server.
- Exclusion on FTP port in a WINDOWS firewall.

LAN requirements at the ResearchCenter

- Permanent access to the Internet
- Static IP address on the WAN side.
- Router with NAT function – routing the FTP port to the LAN IP address of a computer used as FTP server.

Approximate cost of the system without sensors
Approximate cost of the master controller: 1600 USD
Approximate cost of the terminal controller: 990 USD
Operational overheads: at most 100 USD a year
[determined by the tariff of a GSM communication service provider per unit of transmitted data through the GPRS and SMS channels as well as by the operation mode (combination of parameters Qc, Tacq, and Qs - see below) and frequency of use of SMS messages]

Research Center EQP
At the Research Center, a computer permanently connected to the Internet with a static IP address and installed FTP Server software is operating, that enables to gather the acquired data in an EXCEL spread sheet.

Terminal controllers
On an object undergoing the research, "terminal controllers" are installed, the number of which corresponds to that of sensor points. The terminal controllers (see the diagram in Fig. 2) are provided with two 18 bit ΔΣ analogue-to-digital converter (ADC) units (U3) supplied by the company MICROCHIP, where to high accuracy tiltmeters of model 701-2 supplied by the company APPLIED GEOMECHANICS, which enable to measure X and Y components of tectonic transports, are connected. The terminal controllers are built on the basis of 8-bit microcontrollers supplied by the company ATMEL, product line ATMEGA (U5), and programmed with a software specially developed to fulfill the given task. Under the control of the microcontroller, ADC performs every minute conversion of signals obtained from the tiltmeter outputs. The converted data are read by the microcontroller one-by-one from each ADC by means of a multiplexer. Moreover, the microcontroller reads the temperature value from a respective output of the tiltmeter by means of an integrated 10-bit successive-approximation ADC and performs voltage availability control in a power line. All read data are stored in the temporary storage of the microcontroller. On the other hand, the microcontrollers are provided with RS485 (U7) drivers supplied by company MAXIM, to be connected to RS485 bus made in the form of a twisted pair of wires. An unique number is assigned in the programming phase to each terminal controller on the bus. The terminal controllers are provided with LEDs (U4) for detecting the measurement processes locally and voltage availability in the power line, and a slot (U6) for connecting a LCD alphanumeric display capable of displaying all measured real time data. The terminal controllers are powered by AC current line of 220B/50Hz by means of a transformer power source (U1). In addition, they are provided with a rechargeable battery 12B/1.2AH operating in a buffer mode and constantly recharged by a charging circuit with voltage stabilization and current limitation whenever the voltage is available in the power line. The microcontrollers are powered with a DC voltage source of 5 V from a voltage stabilizer (U2).

Master controller
All terminal controllers are united by means of the RS485 bus in a common network controlled by a "master controller" (see the diagram in Fig. 3). The master controller is likewise built on the basis of a 8-bit microcontroller supplied by the company ATMEL, product line ATMEGA (U5), programmed by corresponding software specially developed to fulfill the given task. The master controller is connected to the above mentioned RS485 bus by means of RS485 (U7) driver supplied by the company MAXIM. It is provided with a non-volatile memory (U6) built on the basis of 4 chips supplied by the company ATMEL, each having 65536 bytes of memory, i.e. 262144 bytes of memory amount in total, as well as a GSM/GPRS modem (U4) supporting TCP/IP stack and FTP protocol on the basis of a module Q2406 supplied by the company WAVECOM, also being connected to the common RS485 bus by means of the RS485 (U7) driver. The present solution enables to employ a relatively low-cost microcontroller with a single (merely) integrated UART. The master controller is powered by AC mains 220V/50Hz by means of a power supply unit (U1) equipped with a transformer. Besides, it is provided with a floating battery 12V/1.2AH constantly recharged with a constant-voltage and limit current charging circuit (U1) whenever the voltage is available in the power line. The microcontroller is powered by constant voltage 5 V from a stabilizer (U2). The modem is powered by constant voltage 3.9 V from a stabilizer (U3).

System operation
The master controller interrogates all terminal controllers connected to the RS485 bus in a successive order with predetermined periodicity (see below the parameter Tacq). In accordance with the specification, 32 devices are allowed to be connected to a single RS485 bus and the maximum length of the bus is limited to the value of 1300 meters. The system renders sufficiently manifold possibilities to employ systems built in the same manner. The terminal controllers are interrogated through their unique numbers assigned thereto at the programming stage. Having received the request on its own number, each terminal controller transmits current data – X and Y components

of the tilts, temperature at the sensor point and information on availability of supply-line voltage, from its temporary memory to the bus. The data are exchanged in ASCII format on the bus. Having received the data, the master controller adds serial number of reading, time and date read on a timer and information on availability of supply-line voltage thereto and stores them in the form of a text string in a non-volatile memory. The master controller uses a timer as a clock that is integrated in the modem provided with an additional lithium-ion cell to retain the capability of time reading in lack of power supply. Having acquired the predetermined amount of data (see the parameter Qs below), the master controller establishes communication with a computer at the Research Centre via the modem, and according to FTP protocol, creates in the hard disk memory a text file with the data having been stored in the non-volatile memory at that moment. Thereafter, the master controller cleans up the non-volatile memory and starts to acquire new portion of data. Such method – storing the data in a non-volatile memory and transmitting them to the Research Centre batchwise, enables to save expenses imposed by billing systems of mobile communication service providers on service (protocol) data that are inevitably communicated in both directions in the course of establishment/completion of GPRS communication and opening/closing of FTP session so as to enhance useful traffic. Moreover, it enables to avoid data losses in case of short-term service disturbances in GSM network or on the Internet. Such being the case, in the instance where the master controller fails to establish communication with the Research Centre computer, it resets the modem and retries to accomplish transfer. If the problem persists, it tries again in 30 minutes.
The non-volatile memory storage space allows to store 262144 alphanumeric characters, which means that in case of, for example, 7 terminal controllers on the bus (full record of one reading makes up 207 characters), and of maximal reading rate – 1 reading per minute – corresponds to 21 hours of data acquisition duration, and thus the loss of data can be avoided even in the case of long-term disturbances in communication systems.
The master controller makes access to the FTP server via the Research Centre computer as FTP client with assigned USERNAME and PASSWORD, according to the preliminarily created account in the FTP server clients list. Number of such accounts for a single FTP server is virtually unlimited to link a single computer with infinite number of similar remote data acquisition systems throughout GSM/GPRS coverage area.
The software of the master controller provides for possible management and changing of some parameters remotely via a SMS massage or a call that can be sent to the controllers from a certain mobile numbers. If the received SMS massage contains a command that is valid for the controller, and if it has been sent from an acknowledged number, it responds in accordance with the received command and sends a response to the same number in the form of a SMS report. In addition, the master controller sends on some its own messages in case of certain events.

The master controller supports the following commands:

Info	SMS	requesting the SMS reply containing data on the state and current parameters;
Set	SMS	setting the system parameters;
Nums	SMS	setting the numbers of the mobile phones wherefrom the SMS is received by the controller;
Res	SMS	forcible restarting of the controller and modem (the accumulated data are maintained);
Clr	SMS	cleaning the non-volatile memory;
call	CALL	requesting non-scheduled data transmission;

Example of Command Info
Having received this command, the controller responds with the following type of SMS message:
Info
16.01.12 22:23:15;Y;2458;E00;00;41h;100%;
6;10:00;18:00;10;
7;53;
217.147.238.81;21;UN;PWD;
+995599XXXXXX;+995577XXXXXX;+995593XXXXXX;
The fields of the given message are separated by the symbol ";" (semicolon) and have the following content:

Info	title that determines the cause of the given message
16.01.12 22:23:15	date and time of the message transmission (according to an internal timer)
Y	availability of power to the master controller
2458	total amount of transmitted readings
E00;00	latest error code
41h	available storage amount in hours at a given moment
100%	percentage of the free available storage amount at a given moment
6	Tacq (see the description of the command Set)
10:00	Tm (see the description of the command Set)
18:00	Te (see the description of the command Set)
10	Qs (see the description of the command Set)
7	Qc (see the description of the command Set)
53	Msms (see the description of the command Set)
217.147.238.81	IPftp (see the description of the command Set)
21	PORTftp (see the description of the command Set)
UN	UNftp (see the description of the command Set)
PWD	PWDftp (see the description of the command Set)
+995599XXXXXX	N1 (see the description of the command Nums)
+995577XXXXXX	N2 (see the description of the command Nums)
+995593XXXXXX	N3 (see the description of the command Nums)

Command Set
The non-volatile memory of the microcontroller stores the data defining its operation mode, which can be received remotely via SMS commands. The list of these parameters is given below:

Tacq	-	terminal controllers polling timeslot in minutes;
Tm	-	working day starting time – hh:mm (see the operation algorithm description below);

Te - working day ending time – hh:mm (see the operation algorithm description below);
Qs - amount of data after acquiring of which the controller has to send them to the Research Center;
Qc - quantity of the terminal controllers;
Msms - Mask of some parameters. Transmitted in the form of hexadecimal numerical symbols corresponding to one byte. Values of the bits of this number are given below:
MSb 7 - redundancy
6 - 0 – SMS induced by an event is always sent to the first number
1 - SMS induced by an event is always sent to the number wherefrom the latest SMS has been received
5 - 0 - GSM service provider MAGTICOM
1 - GSM service provider GEOCELL
4 - 1 - everyday congestion of the modem and controller
3 - 1 - messages "FTP err" are allowed (failure at opening the FTP session)
2 - 1 - messages "Power" are allowed (loss/restoring the main power line)
1 - 1 - messages "Start" are allowed (start/restart of the controller in the event of power supply/disturbances or errors)
LSb 0 - 1 - messages "FLASH err" are allowed (errors at accessing to the non-volatile memory of data)
IPftp - WAN IP address of the FTP server at the Research centre;
PORTftp - FTP port number;
UNftp - USERNAME at FTP server for a given object;
PWDftp - PASSWORD at FTP server for a given object;

Example of command Set sent in the form of SMS message:
Set6;10:00;18:00;10;7;53;217.147.238.81;21;UN;PWD; -
after execution of which the following parameters are established:
Terminal controllers sampling rate in minutes: - 6 minutes
Working day start time: - 10:00
Working day end time: - 17:00
Amount of readings after collecting of which the controller has to send them to the Research Center: - 10
Number of the terminal controllers: - 7
Mask: - 53
SMS events are sent to the number wherefrom the latest SMS has been received;
GSM service provider MAGTICOM;
everyday restart of the modem and controller allowed;
messages "Start" allowed;
messages "FLASH err" allowed.
WAN IP address of the FTP server at the Research Center: - 217.147.238.81
FTP port number: - 21
USERNAME at FTP server for a given object: - UN
PASSWORD at FTP server for a given object; - PWD
and the controller responds with the following message:
Set
16.01.12 22:23:15;Y;2458;E00;00;41h;100%;
6;10:00;18:00;10;
7;53;
217.147.238.81;21;UN;PWD;
+995599XXXXXX;+995577XXXXXX;+995593XXXXXX;
After this command, the master controller will read data from the terminal controllers every 6 minutes (Tacq), and will transmit to the Research Centre the chunk of data consisting of 10 latest readings (Qs), i.e. the data will be sent once in an hour – 10 latest readings at once. The entire non-volatile memory is sufficient for storing the data for 211 hours.

Command Nums
3 mobile phone numbers are also stored in the non-volatile memory of the microcontroller, through which SMS messages are received by the controller:
N1 - Number of the first mobile phone wherefrom the SMS is received by the controller;
N2 - Number of the second mobile phone wherefrom the SMS is received by the controller;
N3 - Number of the third mobile phone wherefrom the SMS is received by the controller;
An example of command Nums is given below:
Nums995599XXXXXX;+995577XXXXXX;+995593XXXXXX; - after execution of which the following numbers are established:
Number of the first mobile phone wherefrom the SMS is received by the controller: - +995599XXXXXX
Number of the second mobile phone wherefrom the SMS is received by the controller: - +995577XXXXXX
Number of the third mobile phone wherefrom the SMS is received by the controller: - +995593XXXXXX
and the controller responds with the following message:
Set
16.01.12 22:23:15;Y;2458;E00;00;41h;100%;
6;10:00;18:00;10;
7;53;
217.147.238.81;21;UN;PWD;
+995599XXXXXX;+995577XXXXXX;+995593XXXXXX;

SMS messages induced by events
The master controller can send unsolicited SMS messages in case of certain events depending on the value of the parameter Msms. On all occasions, the SMS contents are similar to the case with the command Info, except for the

title, which can be as follows:
Start - start/restart of the controller occurred due to the power supply/disturbances or errors;
Power - loss or occurrence of line supply;
FTP err - transmission of the data to the server failed;
FL err - error occurred at accessing to the non-volatile memory;
Mem crit- non-volatile memory is filled to capacity – 90% (can occur in three cases if the controller fails to transmit the data to the server for a long while).

The master controller operation algorithm
The master controller polls the terminal controllers and reads the data in timeslots Tacq, adds a serial number of reading, time and date read on a timer integrated in the modem, and information on availability of supply-line voltage thereto and stores them in the form of a text string in a non-volatile memory. Whenever the number of the readings stored in the non-volatile memory reaches the value defined by the parameter Qs, the controller checks the current time, and in case it falls within the working day (>Tm and <Te), starts to establish connection with the server to transmit the data. Such organization of the operation mode envisioning the working hours of the Research Centre allows to keep the server computer switched off outside of working hours if not necessary (the data received in non-working hours never can be handled by the personnel in the Research Centre until the next working day) and, thereby, to save electric power and computer resources. In case of successful transmission of all data, the controller releases the non-volatile memory and starts to acquire new data in the same mode.

In case of failure or loss of connection with the server that leads to the failure of transmitting the complete data, the master controller restarts the modem and microprocessor in an attempt to establish the connection once again. In case of repeated failure, an SMS message with a title "FTP err" (if it is allowed by the parameter Msms) will be sent, and the attempt will be repeated in 30 minutes (if the shorter time is not defined by the combination of parameters Tacq and Qs). Meanwhile, it keeps acquiring the data from the terminal controllers and stores them in the non-volatile memory. This will be repeated until the end of the working day.

If for a long time the controller fails to send the data and the non-volatile memory is filled to capacity – 90%, the controller sends the message "Mem crit" and reattempts to send the data notwithstanding the working hours. The attempts will be repeated two times every 30 minutes after restarting the modem and microprocessor.

This process will run over and over again until successful transmission of the data and filling the memory completely. In the latter case, the memory is cleaned, the data are lost and the process continues to run in ordinary way.

Correction of time in the integrated timer is performed automatically after each sent SMS, using the time of read from Delivery Report SMS containing the true time from the SMS service centre.

2. Possible alternative realizations of the system
In case where the objects that undergo research allow to use the Internet connection, the master controller can be built by use of an Ethernet controller instead of a GSM/GPRS modem to allow lowering the operation costs due to the lower costs of data transmission and receiving readings in practically real time without the need of the non-volatile memory.

If the specificity of the parameters measured on an object that undergoes the monitoring requires the higher reading rate, the circuitry and software of the master and terminal controllers can be built in such a manner as to allow 1 reading per second. However, the amount of the non-volatile memory must be larger in this case. This problem can be solved by adapting the master controller in a manner as to allow using SD card as a non-volatile memory and, thereby, increasing the memory amount up to several gigabytes.

In the present realization, the system reads the data from sensors having analogue outputs. Any sensors (other than aforementioned) having analogue outputs within the range of +/-14,3V can be used as well. Moreover, the system can be modified so as to be adapted to sensors having any other types of outputs, e.g. with sensors having a current output and various digital protocols.

It should be noted that the aforementioned modifications of the system and its components will affect (increase) the cost of the software and hardware

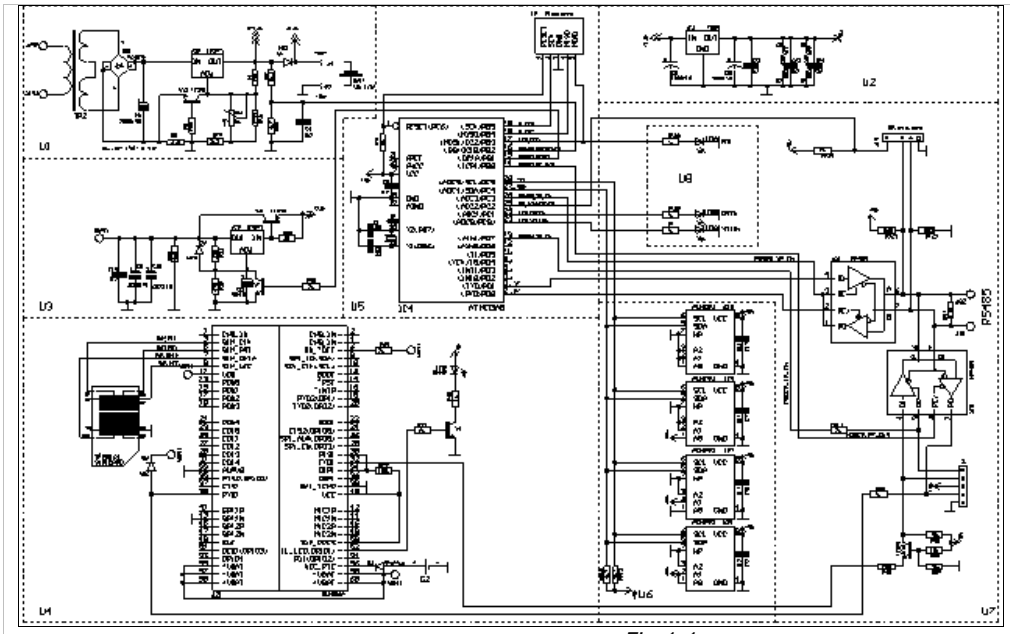


Fig.1.1

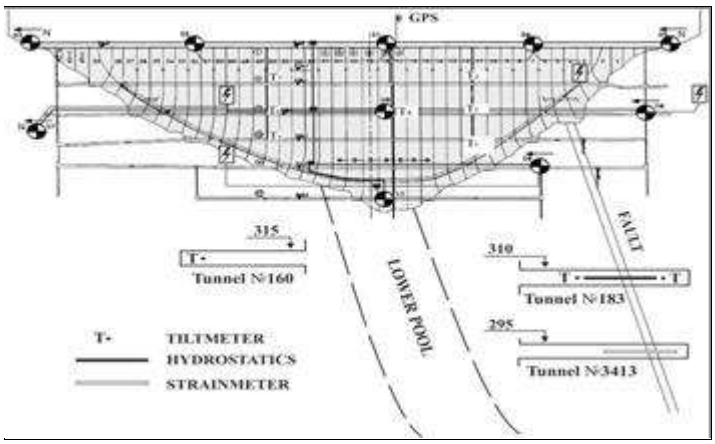


Fig.2.1. Scheme of monitoring network at EDITA, numbers show location of accelerometers and T - location of tiltmeters (downstream view).

Permanent acquisition of analogue signal measurements from sensors (tiltmeters, strainmeters, vibrometers) and finding, whether the latter ones are representative for the main characteristics of construction's mechanical behavior. Creation of long enough data bases of tilts, strains and low-frequency vibrations for linear/nonlinear analysis.
Scheme of monitoring network at EDITA, is shown in Fig.2.1: numbers show location of accelerometers and T - location of tiltmeters (downstream view). The data from 7 tiltmeters located in the body of the dam are regularly transferred by the system DAMWATC to the diadnostic centre. The typical electronic table of data is presented below. The long enough data base (almost two years long) has been compiled.

Date Time	X1	Y1	T1	X2	Y2	T2	X3	Y3	T3		
08.04.10		0:00:01	0.00	0.00	12.4	0.00	0.00	12.7	0.00	0.00	13.7
08.04.10		0:01:00	-0.01	0.00	12.4	0.00	0.00	12.7	0.41	0.33	13.7
08.04.10		0:02:00	0.00	0.01	12.4	-0.03	-0.01	12.7	0.00	-0.05	13.7
08.04.10		0:03:00	0.00	0.01	12.4	-0.03	-0.01	12.7	0.18	-0.08	13.7
08.04.10		0:04:01	-0.03	0.00	12.4	-0.05	-0.01	12.7	0.55	0.14	13.7
08.04.10		0:05:00	-0.01	0.00	12.4	-0.01	-0.02	12.7	0.43	0.06	13.7
08.04.10		0:06:01	0.00	0.01	12.4	-0.01	-0.01	12.7	0.02	0.01	13.7
08.04.10		0:07:01	0.02	0.01	12.4	-0.03	-0.01	12.7	0.62	0.08	13.7
08.04.10		0:08:01	0.01	0.00	12.4	-0.03	-0.01	12.7	1.09	0.36	13.7
08.04.10		0:09:00	0.01	-0.01	12.4	-0.05	-0.03	12.7	0.45	0.09	13.7
08.04.10		0:10:01	0.00	0.00	12.4	-0.04	-0.02	12.7	0.57	0.12	13.7
08.04.10		0:11:00	0.01	0.01	12.4	-0.04	-0.01	12.7	0.13	-0.05	13.7
08.04.10		0:12:01	0.00	0.00	12.4	-0.02	-0.01	12.7	0.81	-0.05	13.7
08.04.10		0:13:00	0.01	0.00	12.4	0.00	0.00	12.7	0.11	-0.13	13.7
08.04.10		0:14:01	0.01	0.01	12.4	-0.02	-0.01	12.7	0.42	-0.01	13.7

3. Creation and development of the 3rd static mathematical model of construction taking into account: geometric parameters; construction material properties, geologic conditions of foundation; operation loads of different origin. Comparative analysis of measured and predicted (by deterministic model-FEM, linear and nonlinear forecasting) data sets in order to derive the main statistical and dynamical features of construction's behaviour patterns and to ensure appropriate decision making.

During to the project 3 goals were accomplishment.1. Creation of "Enguri arch dam–foundation system" FEM model; 2. Retrospective analysis of dam deformation dynamics at various loading conditions; comparison of measured and FEM data; 3. Definition of the range of significant departures of dam dynamical characteristics from FEM-predicted, which will signal damage and approaching the pre-failure state;

Creation of "Arch dam - foundation" finite element model
By use of topographical map the following was determined: - levels of characterizing points of foundation shape;- parameters of dam abutment. The 3D model of system "Dam-foundation" has been developed. The foundation model takes into consideration homogeneity areas manly represented by 4 layers areas according the geological cross sections. The dam calculating scheme's vertical lines are created according the arch dam structure cantilevers including gaps. The horizontal lines orientated towered the boundaries of constriction concreting blocks (Fig. 3.1).

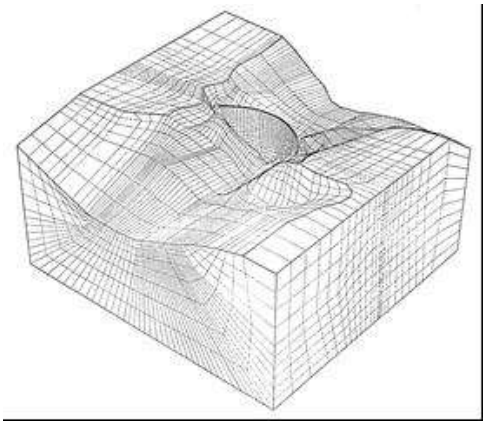


Fig. 3.1. Enguri "dam-foundation" 3D model.

In general, FEM calculations agree with observations of monitoring network on lower levels of the dam, but there are some problems at higher (closest to top) levels, where observed values exceed theoretical assessments for critical strains. At the same time the dam performs normally without any serious visual damage. This means that theoretical model should be re-considered.

Work package 2 (prepared by ECNTRM, ECILS, CEPRIS, ECRP):
Collection and exchange of information on the dam monitoring system for their respective country; selection of the dam to develop there real-time monitoring complex and complex of linear/nonlinear dynamics data processing methods for construction diagnostics;
Information on the dam monitoring system in for their respective country; selection of the dam to develop there real-time monitoring; assimilation of complex of linear/nonlinear dynamics data processing methods for construction diagnostics;

Deliverables:

Bulgaria
ECPR collected the information concerning dams in Bulgaria. They are managed mainly by four ministries:

- The Ministry of Economy, Energy and Tourism: 43 dams of the National Electricity Company;
- The Ministry of Agriculture and Food (Irrigation systems);
- The Ministry of Environment and Water;
- Ministry of Regional Development and Public Works.

These ministries issue a Regulation on the terms and conditions for implementation of the technical operation of the dam walls and installations. This regulation determines the main parameters of the dam walls monitoring system in Bulgaria.

Classification of the dam walls and the related installations:

1. Depending on the type of the construction:
   - Gravitational – dam walls of concrete or embankment;
   - Counterforce – massive and multi-arch;
   - Arch.
2. Depending on the construction materials and the technology of construction:
   - Concrete – massive of conventional concrete or rolled concrete, massive lightened, massive – counterforce type "Nötzli" and arch;
   - Embankment – earth, stone and mixed;
   - Masonry;
   - Inwash.

Large dam walls are determined depending on their summarized parameters – height, length along the top, volume of the water storage, in accordance with the classification of the International Commission on large Dams (ICOLD).
The classification of the dam walls and the related installations depending on the consequences in case of a failure and/or destruction is performed in accordance with the "Norms on Design of Hydrotechnical Installations" in Bulgaria.
The Water Act indicates a list of 52 complex and important dams, monitored by the Ministry of Environment and Water.
The dam walls and the related installations are categorized in accordance with the Territory Organization Act. The requirements for assurance of their security are determined in the project for operation and maintenance and the operating instructions. The person implementing the technical operation provides periodical assessment of the risk of compromising or destruction of the dam walls and the related installations depending on:
1. The updated hydrological information;
2. The changes in the seismological information;
3. The changes in the quality of the foundation, the construction materials and the construction;
4. The changes as a result of anthropogenic activity;
5. The results from the measurements and assessment of the operation of the Instrumentation Systems /IS/.

The risk during operation of dam walls and the related installations is determined by:
- The likelihood of occurrence of natural disasters;
- The specific topographic and geological conditions and the construction of the installations;
- The specific human activity.

The security under the conditions of operation is assessed through monitoring and control of indicators for:
- Their constructive security;
- Their technological security;
- Their impact on the environment.

The constructive security is the ability of the dam walls and the related installations and their foundation to retain:
- General local strength, carrying capacity;
- General resistance;
- Filtration resistance;
- Cracking resistance;
- Hardness;
- Fatigue effect strength;
- Frost resistance;
- Corrosion resistance;
- Wearing resistance;
- Temperature resistance;
- Bio-corrosion resistance.

The technological security is the ability to perform their main functions according to indicators for:
- Geometrical conformity with the design (dam wall ridge altitude, highest altitude of the anti-filtration device, water level altitude, head, slopes, permeability, etc.);
- Conformity with the properties of the materials (strength, water-tightness, head gradients, filtration coefficient);
- Technological term of operation.

The indicators for constructive and technological security and for preservation of the environment are determined in the project documentation:
- The person implementing the technical operation monitors for the occurrence of qualitative and quantitative signs of deviation from the indicators in the project for operation and maintenance and the operating instructions;
- The parameters controlled within the period of operation are compared to the design and forecast values obtained on the grounds of data from previous monitoring and measurements.

The assessment of the security of dam walls and the related installations includes:
- Updating of the classification of the installation;
- Analysis of the results from the inspections of the technical state;
- Analysis of the results of the operation of the Instrumentation Systems and the database from the monitoring;
- Assessment of the methods for monitoring and control;
- Assessment of the operating instructions;
- Assessment of the results from the performance of periodic inspections of the state of all types of equipment;
- Assessment of the results from inspections of the readiness of action groups according to the emergency plan and simulation of an emergency situation;
- Assessment of results from inspections of the compliance with the directions from previous analyses of the security;
- Drawing up of conclusions and recommendations.

An emergency plan for action in case of extreme and emergency situations is developed. The activities on realization of the meteorological and hydrological monitoring are performed in observation of the requirements of the International Organization for Standardization and the World Meteorological Organization.

Technical monitoring during operation of the dam walls and the related installations
The technical monitoring provides information for assessment of the security of the dam walls and the related

installations with the possibility for simultaneous identification of potential dangers. For each dam wall and the related installations equipped with Instrumentation Systems there is a separate database with measurements, which is maintained and periodically updated. For interrelated events the database contains synchronized measurements from the technical, meteorological and hydrological monitoring.
The technical monitoring /the observations and measurements, their analysis and assessment/ covers the dam wall and the related installations, the geological foundation and the coasts in the areas of effect in the upper and lower section. The observations and measurements related to the technical monitoring of dam walls and the related installations are:

- Obligatory;
- Periodic and constant;
- Simultaneous during observations and measurements of interrelated events;
- Comparable by time, hour and place.

The Instrumentation System (IS) is executed on the grounds of a design, an integral part of the project.
The organization of the observations and measurements provides:

- The measurements of the processes and events occurring, as foreseen in the project for operation;
- The possibility for simultaneous measurement of a specific event with at least two devices from the IS;
- The possibility for a reliable assessment of the measured processes and events;
- Gathering of information for an overall assessment of the state of the dam walls and the related installations.

The observations and measurements are performed in accordance with the program for technical control on three levels:

- Visual control – determined by place and time;
- Operative measurements in specific points;
- Full measurements of all monitored points according to the IS project and the operating instructions.

The measurements of newly constructed dam walls and the related installations are direct and remote, without or with a Central Measurement Station. In the case of old dam walls, when possible, the IS is gradually connected to the Central Measurement Station. The technical monitoring of concrete dam walls includes observations and measurements of:

- The water level in the water storage;
- Filling of the water storage with deposits;
- Horizontal and vertical shifting;
- Reciprocal shifting between wall and foundation;
- Development of cracks in the wall;
- State of the joints;
- Water raise and pressure;
- Change in the quality of the concrete and the foundation;
- Filtration and leaks through, under and around the wall;
- Turbidity and chemical composition of the filtrated water;
- Deformations and tensions in the body of the wall;
- Deformations of the foundation;
- Temperature of the concrete, the water and the air;
- Seismic impacts.

The technical monitoring of dam walls from local materials includes observations and measurements of:

- The water level in the water storage;
- Filling of the water storage with deposits;
- Water back pressure;
- Filtration under and around the wall;
- Filtration through the body of the wall;
- Turbidity and chemical composition of the filtrated water;
- Position of the depression surface;
- Steam /hydrodynamic/ pressure;
- Horizontal and vertical shifting;
- Change in the quality of the embankment and the foundation;
- Deformations and disruption of the solidity of concrete installations to the wall;
- Deformations and tensions in the embankment;
- Seismic impacts.

The periodicity of observations and measurements is indicated in the program for technical control in accordance with:

- The category of the installation;
- The dynamics of the water level in the dam;
- Occurrence of an extraordinary event.

If there are no other directions, observations and measurements with IS are performed no less than:

- Once every three months for large dam walls;
- Once every six months for small dam walls.

In the case of new dam walls the measurements are performed in accordance with a special schedule.
The volume, type, form and manner of documentation of the results from the measurements are determined in the project for operation and maintenance of the IS. All observations and reports are recorded in the respective journal /form/ prior to and after the primary processing performed by the operating group. The results of all observations and reports, as well as their primary processing performed by the operating group, are recorded in the existing database and on paper.

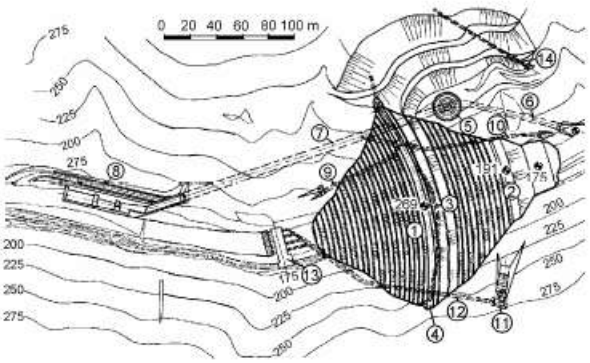
Potential object of study
CHAIRA DAM in Bulgaria has been officially proposed by :

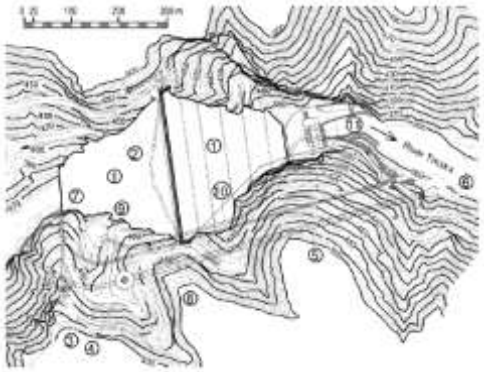
BASIC DATA	
Location	Rila Mountains
Built on	Chairska River
Water catchment area, square km	18,6
Mean annual inflow, cub. m/s	1985-1988
Use	electricity generation
Water masses regulation	daily by reversible pressure tunnel - Yadenitsa Dam
WATER STORAGE	
Total storage, mln. cub. m	5,60
Usable storage, mln. cub. m	4,20
Max. water level, m	1261,30
Max. operational water level, m	1260,0
DAM	
Type	concrete, gravity dam
Waterproof component	grout curtain
Height from foundation, m	85,0
Crest length, m	305,0
Crest level, m	1263,0

"The former Yugoslav Republic of Macedonia"
ECILS studied the suggested technology and is interested in the implementation. Potential object is not selected yet but two alternatives dams has been preselected by ECILS:

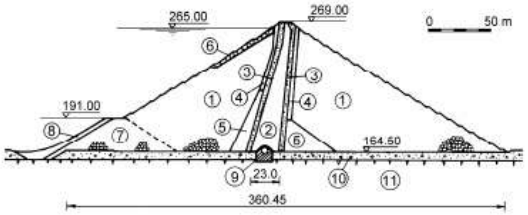
Dam: Tikveš
Structural height: 113.5m
Type: Earth-rock dam (E-R)
River: Crna Reka
Constructed: 1968

Dam: Kozjak
Structural height: 126m
Type: Earth-rock dam (E-R)
River: Treska
Constructed: 2004

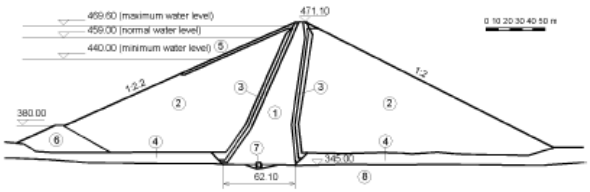




(1) Dam body; (2) upstream cofferdam; (3) layout if the grout curtain; (4) dam crest axis; (5) spillway shaft; (6) diversion tunnel; (7) spillway tunnel; (8) stilling basin; (9) access gallery; (10) bottom outlet; (11) intake structure; (12) head-race tunnel; (13) power house; (14) irrigation tunnel



(1) Rockfill; (2) clay core; (3) filter layer I; (4) filter layer II;
(5) stone chippings; (6) coarse stones; (7) cofferdam of rockfill; (8) clay screen of cofferdam; (9) concrete block with a grouting gallery; (10) river sediment; (11) rock foundation



(1) Rockfill; (2) clay core; (3) filter layer I; (4) filter layer II;
(5) stone chippings; (6) coarse stones; (7) cofferdam of rockfill; (8) clay screen of cofferdam; (9) concrete block with a grouting gallery; (10) river sediment; (11) rock foundation

Morocco
CEPRIS studied the suggested technology and is interested in the implementation. Potential object is not selected yet.

Russian Federation
ECNTRM studied the technology suggested by GHHD and decided that Russia has its own technology for monitoring engineering objects and it is not interested in the project.

ACTIVITIES PLANNED IN 2013 (split by partner)

Working package 1 (prepared by GHHD, ECNTRM, ECILS, ECRP, CEPRIS):
Description:
GHHD: Compilation of data-base of recordings of sensors (tiltmeters, strainmeters, vibrometers) at EDITA and the selected objects in partner countries for an year 2013. Selection/development of data analysis linear (frequency, time-frequency, singular value decomposition, autocorrelation first zero crossing variation, etc.) and nonlinear (phase space structure, phase trajectory evolution, noise reduction, memory, long range correlation testing, etc.) methods, appropriate for measured tilt, strain, vibration meter data sets during one year load-unload cycle in order to establish construction response to water load. Selection of appropriate to the targeted problem linear (autoregressive) and nonlinear (based on topology of reconstructed attractor) forecasting methods and creation of special diagnostic toolbox for analysis of tilt/strain time series.
ECNTRM: compilation of monitoring data base on selected object; assimilation of special of linear/nonlinear dynamics diagnostic toolbox for analysis of monitoring time series and application to selected dam to develop criteria of stable functioning of construction
ECILS: compilation of monitoring data base on selected object; assimilation of special of linear/nonlinear dynamics diagnostic toolbox for analysis of monitoring time series and application to selected dam to develop criteria of stable functioning of construction
ECRP: compilation of monitoring data base on selected object; assimilation of special of linear/nonlinear dynamics diagnostic toolbox for analysis of monitoring time series and application to selected dam to develop criteria of stable functioning of construction
CEPRIS: compilation of monitoring data base on selected object; assimilation of special of linear/nonlinear dynamics diagnostic toolbox for analysis of monitoring time series and application to selected dam to develop criteria of stable functioning of construction
Associated deliverables: