Chapter 14

Tools for Rock Fall Risk Integrated Management in Sandstone Landscape of Bohemian Switzerland National Park, Czech Republic (M121)

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Abstract. There are 327 monitored rock objects with more than 900 measuring sites on the territory of Bohemian Switzerland NP and its nearest neighborhood, and the monitoring nets are ever growing. Therefore a high-tech, scientifically challenging Integrated System (IS) of effective, but nature-friendly management of rock fall risks on the Bohemian Switzerland NP territory has been under construction since 2002, there. Rapid processing and timely, on-line delivery of relevant, easy-to-understand information to an end-user through an information web portal and cellular phone emergency messages should be the highlights of IS. Other highlights are represented by the implementation of complex dynamical systems knowledge and methods to provide more realistic and mathematically more rigorous grasping of very complex dynamics of rock slope stability failure. Moreover, they also provide a basis for a qualitative step in implementation of computers for future highly automated run of data assessment, modeling and early warning modules of the system. Several successful case-histories have made those new tools very promising for the practical use. Nevertheless, there are some tasks still unfinished. Especially the one enabling to bridge the gap between science, civil protection and general public and by it to enhanced effectiveness of utilization of delivered information by its end-users.

Keywords. Rock fall, holistic approach, risk assessment spatial and time domains, monitoring, early warning, forecasting, Czech Republic

14.1 Introduction

Specific sandstone landscape with plateaus, deep canyons, rock cities and labyrinths, which has developed on massive, sub-horizontally stratified sandstones of Cretaceous age, and the rich eco-diversity related with this landscape have been protected within the frame of Bohemian Switzerland National Park in NW Bohemia. Picturesque, tourist attracting, high-energy relief with rock walls on valley sides of deep canyons and on rims of plateau-mountains is conditioning frequent occurrence of rock falls, there. Nowadays, preparation of those rock falls is causally connected with activity of exogenous geological processes, mainly with weathering and erosional removal of materials at rock wall toes (Vařilová 2002; Vařilová and Zvelebil 2005a).

At one hand, those rock falls belong to a contemporary, natural development of sandstone landscape, so they are an integral part of the protected natural environment. On the other hand, there is also a strong need to protect safety of inhabitants and visitors of the National Park. To fulfill both those tasks, a program to establish an integrated system of effective, but nature-friendly management of rock fall risks has been launched on the Bohemian Switzerland NP territory.

14.2 Integration Issue

Geo-risk management is always a multidisciplinary task, which has to fulfill in the same time four different tasks.

On one hand, a multi-disaster approach should be used to tackle as with the multi-causal origin of individual types of disasters together with very rich spectre of spatial-temporal scales, within them those disasters are being prepared and act, as with the possibility of causal chaining of the individual disasters into one spatial-temporal sequence of threads (e.g. meteorological disastrous event – flood and landslide/rock fall events – transport and agriculture infrastructure collapses etc.). Therefore, the scientific part of that management should integrate knowledge and methods from various fields of geosciences.

On the other hand, outcomes of complex, scientific effort should be delivered to their practical end-users – i.e. to National Park administration, municipalities and other executive entities, in an understandable, simple, ready-to-use form. Easy to comprehend, concise, mainly graphic forms should be implemented or developed to fulfill this task.

Timely delivery of information (from data to be analyzed to early warning launching for public) is an essential demand of both the previous management tasks. Information turnout should be as rapid as possible. Therefore, progressive Information Technologies (IT) should be implemented for an automated data acquisition, online transport, data multiple analyzes, and synthesis of data from different sources in the integrated process of their final evaluation, and consequent transformation of the most important scientific results into the simple, end-user fitted forms.

At last but not at least, operation of the system should be, besides all its above listed functions, also reasonably priced.

14.3 System Structure, Methods, Outputs

Scheme of the system is depicted on Fig. 14.1.The system is forwarding the best practices as they had emerged from the forerunning task to secure a traffic corridor going through a deep canyon of the Labe River between Děčín Town and Czech-Germany boundary-crossing point (Zvelebil 1995; Zvelebil and Park 2001).

14.3.1 Regional Rock Fall Risk Zoning in Spatial Domain, 1 : 10 000

Areas at different level prone to preparation of various types of rock falls are identified within the frame of *rock fall hazard zoning*. In the same time, areas of special interest are demarcated within the former ones – i.e. especially populated areas, traffic corridors, and along main tourist trails are demarcated. Finally, *rock fall risk zoning* is produced combining the rock fall hazards with probable negative consequences of those hazards for those special interest areas (Fig. 14.2).

The rock fall hazard zoning is based on the principle of geomorphologic developmental units. It is more complex – hence more realistic, than the current simple zoning by spatially and causally linear overlying of different GIS layers, because it is adding a historical-genetic description of reaching the present day slope conditions. Regional model of development of sandstone slopes with regards to spatially and mainly temporally differentiated activity of destructive processes, especially of rock falls, within its course (Zvelebil 1989; Zvelebil and Vařilová 2005a) is exploited for the latter task. The zones defining of differentiated occurrence probability for distinct types of rock fall match according with that method, with zones demarcating areas in selected stages of rock walls development, because different developmental stages are characterized by domination or diminishing of different rock fall types among slope shaping, destructive processes.

Resulted rock fall hazard maps are therefore valid for the time-spans characterizing development of sandstone slopes – i.e. minimally for hundreds, but more probably for thousands and more years. This long validity time span of the rock fall hazard maps makes them the up-date-non-demanding ones in the frame of rock fall risk management tasks. The only exception should be made for any enhancement of knowledge of regional rock slope development model and causal associations of rock fall occurrences with developmental stages of that model.

14.3.2 Detailed Risk Zoning in Spatial-Temporal Domains, 1 : 1 000, 1 : 2 000

In areas of high rock fall risk, detailed *engineering-geological mapping of rock slopes with unstable objects inventory* are carried out. For each inventoried object, its actual instability is fixed using the four degree scale (Fig. 14.3). This instability scale already embodies the time aspect expressed in the human time scales. Simple, numerical equilibrium calculations are combined with empirical-phenomenological models of failure development in sandstone slope to that time assessment: *(x)* immediately

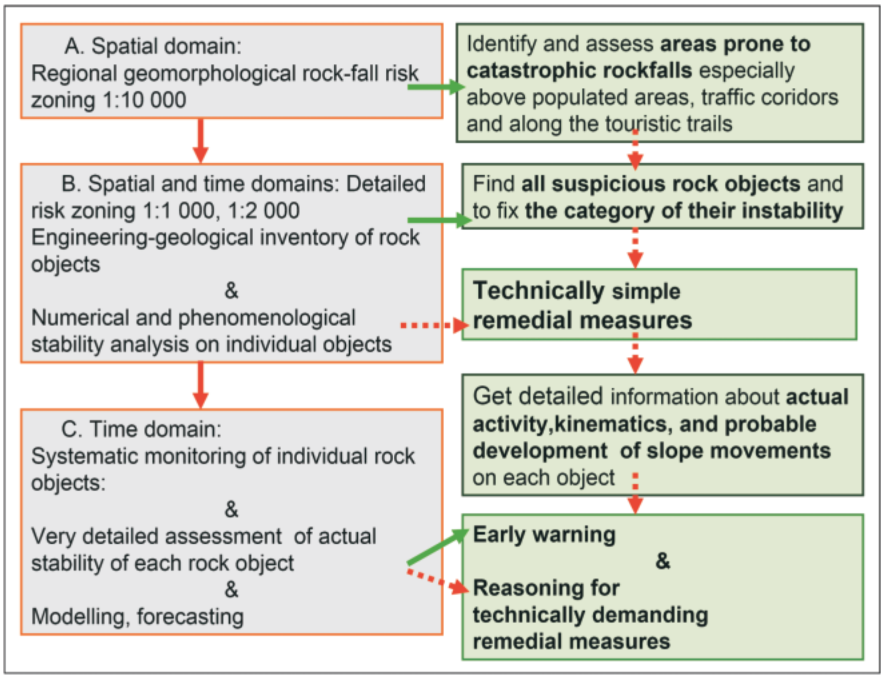

Fig. 14.1. Block function scheme of the Integrated System for Rock Fall Risk Management, which is being implemented in the Bohemian Switzerland National Park

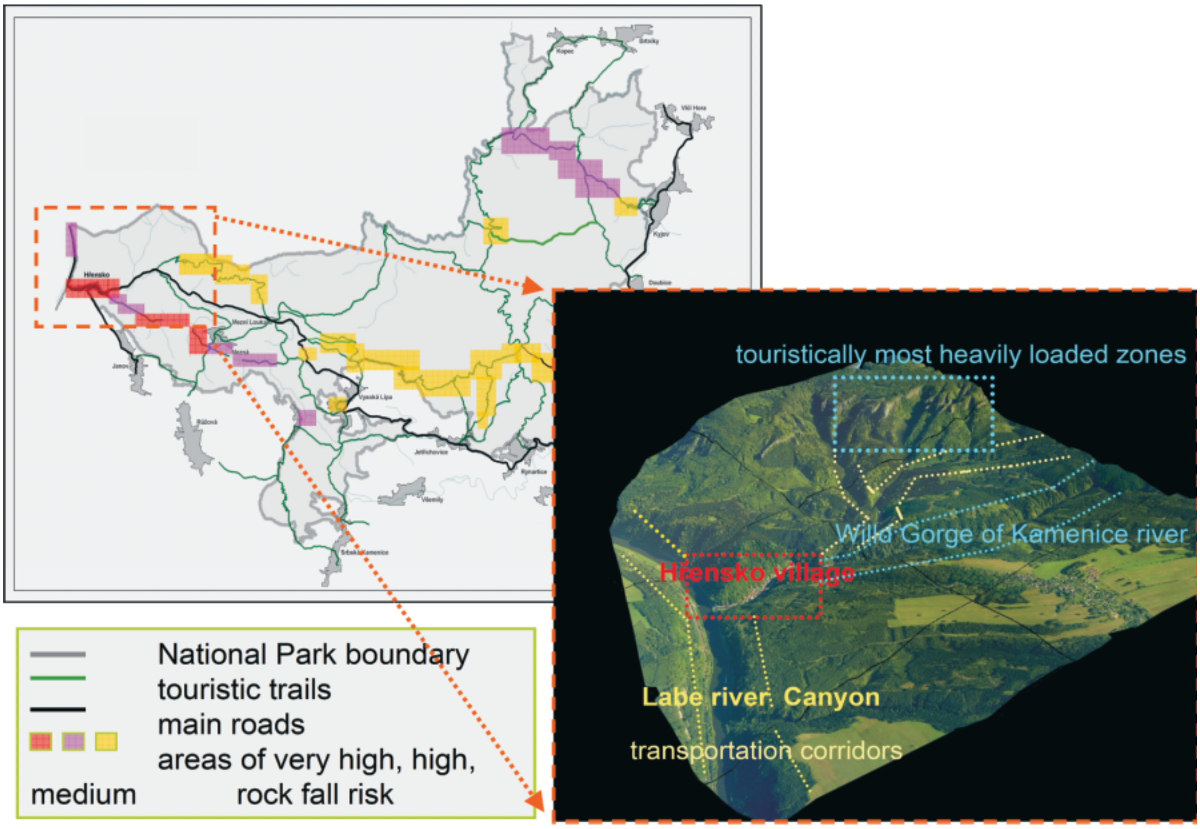

Fig. 14.2. Map depicting distribution of rock fall risk in key areas of the National Park territory. The map was constructed by combination of GIS layer for areas of special interest around settlements, traffic corridors and the main tourist trails, with layers depicting rock fall risks. The *red box* on map and the picture of DEM represent the area of Hřensko Village (cf. Fig. 14.3) and its neighborhood, which is the most important area of thorough rock fall management within the Park territory

unstable objects possess no safety warranty. They could collapse any time within the time span from a few days to a few months. As such objects are classified the ones which posses as the high degree of calculated instability, as clearly visible demonstrations of activity of rock mass destruction and its strength decay (fresh shattering, propagation of new joints, splitting off etc.) within the statically key areas of rock object under evaluation. *(xx)* The second category of objects provides a reasonable degree of security against unexpected rock fall occurrence for time spans of months, maximally of one year. The objects with the same class of numerically fixed instability as in the previous category but without those signs of fresh degradation of rock mass strength represent this second category. *(xxx)* The third category should provide the security for time spans up to 3–4 years. It embodies objects without visible signs of degradation of their rock mass strength and with very small stability reserve. *(xxxx)* The forth category grants security from 4 years up to a few tens of years.

Regarding the time aspects of the listed instability scale, validity of the inventory maps of dangerous rock objects is restricted to 2–3 years. After its expiration, those maps should be up-dated.

14.3.3 Very Detailed Risk Assessment in Time Domain

Only two categories of unstable objects are immediately technically treated – or stabilized or removed, just after the delivery of results of the detailed risk zoning in spatial-temporal domains: *(i)* the unquestionably immediately unstable objects; *(ii)* potentially unstable object of the second and the second and third category objects on condition that their volumes and positions as provide conditions for cheap and simple technical treatment and, in the same time, their monitoring would or uneconomical, or low reliable one due to the small rock volumes activated by the instability development.

All the other objects are moved to the *group of systematically, by monitoring supervised rock objects* to further refinement of their risk assessment in a time domain. This wide implementation of monitoring brings following multiple practical use. It provides: *(i)* an instant security against an occurrence of unexpected rock falls, even from its very beginning; *(ii)* information as about a real activity of mass disturbation, as about its dynamics, kinematics, as well as its magnitude, dynamical patterns includ-

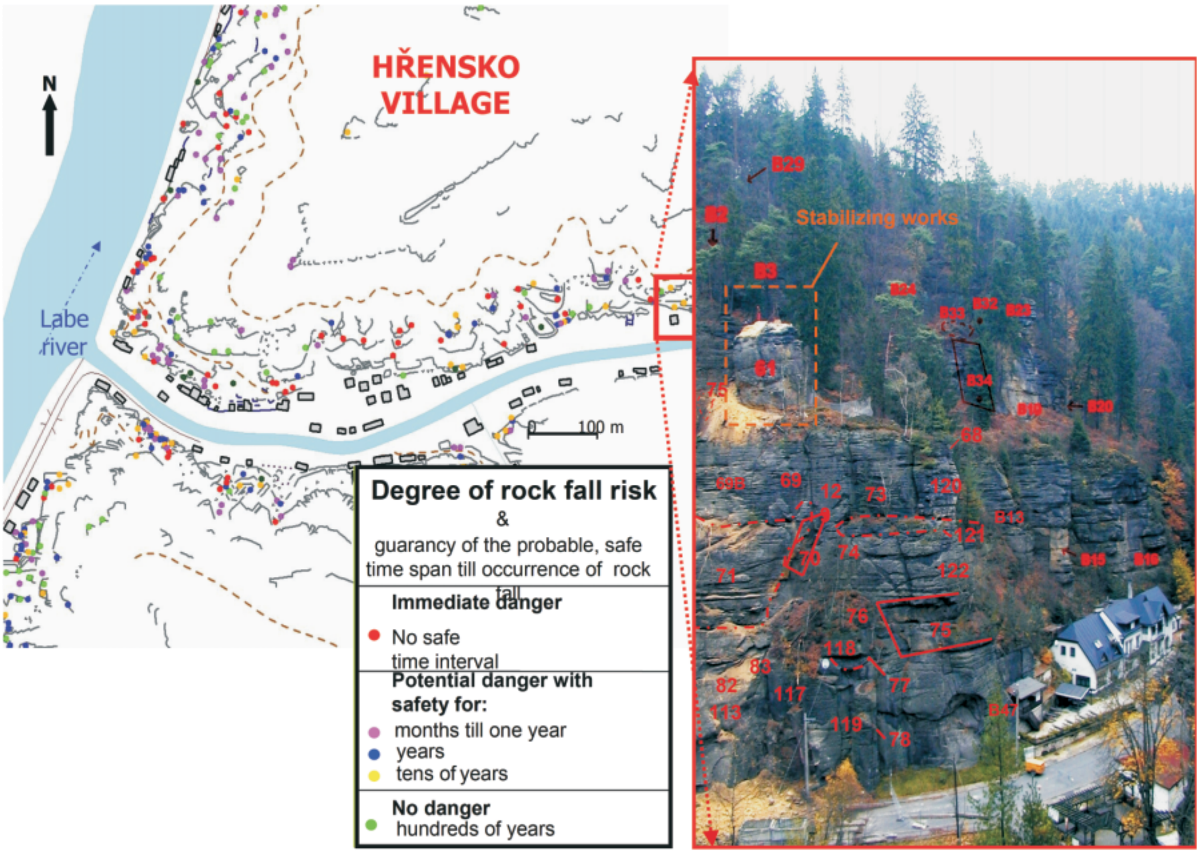

Fig. 14.3. Part of detailed engineering geological map of slopes and unstable rock object inventory in Hřensko Village, 1 : 1 000. The *red box* marks the detail of area presented on the photo. In the *left upper half* of the photo, notice please, a simple remedial measure taking place – the gradual, from *top downwards* advancing removal of immediately dangerous rock tower no. 61 by a group of professional alpinists

ing possible triggering factors for its accelerating events; *(iii)* Information according the paragraph *(ii)* enables as further refinement of actual instability and security degree for the monitored objects, as well as provides basic input data to time forecasting of rock fall occurrence *(iv)*. By providing information listed, monitoring also helps to substantially lower uncertainties in input data and to compensate some other drawbacks of geomechanical computing schemes for rock slope stability evaluation, and for planning of optimal remedial measures. During their realizations, it provides not only security for workers, but also for an operational optimization of those works). Finally, it could be used for checking of their stabilizing efficiency.

Monitoring techniques include portable rod dilatometer measurements, which represent the main method, portable tilt-meter and extensometric tape measurements. Recently, an automated, complex system for remote, on-line data acquisition and Internet DB Storage, data processing, and on-line, interactive result visualizations, including the end-practical-user fitted simple graphical forms, has being introduced.

Displacements between rock blocks on selected, kinematically and safety key-sites of rock object are measures together with selected items of micro-climatic characteristics are systematically measured to detect existence of any irreversible deformation and to fix its magnitude and dynamical patterns. Temperature changes are the main environmental influence measured. Temperature has been proved as to be the main driving force for reversible deformation by voluminal changes of rock blocks and thus spoiling the information about intrinsic slope movement dynamics, as to probably taking part in dynamic driving of the intrinsic dynamics of slope failure system in its Near-To-Equilibrium stage (see Paluš et al. 2004).

Dynamical Systems theory and holistic phenomenological models are used as for the assessment of instant instability of rock objects due to detecting the actual developmental stage of rock fall preparation on them, as that process modeling for purpose of its short- and medium-time forecasting. Different developmental stages of rock fall preparation, including the early warning precursors of rock fall occurrence, are detected using characteristic differences in slope movement dynamics. Quite *reliable* *diagnostic of immediate danger state, as well as its short- and medium-time forecasting* (from days to 2 years ahead) are at our disposal now. Current phenomenological models, which implantation is rather hand-made work demanding the high skilled personnel (e.g. Zvelebil 1996; Zvelebil and Moser 2001) have been now accompanying by mathematically rigorous numerical analyzes and modeling according the latest challenges of complex dynamical systems theory (Paluš et al. 2004; Zvelebil et al. in print, also cf. "Discussion" section).

Besides the data effective storage, synthesis and evaluation, the GIS systems also provide a basis for an interactive, on-line presentation of the final maps with plots of all monitored objects together with actual monitoring data and their safety evaluation for every object. The first experimental version of specialized web portal has been already launched. The site is accessible only to authorized persons from NP Administrations and Ministry of Environment. For area of Hřensko Village (cf. Fig. 14.3), it provides on-line, hierarchically interactive information about results of detailed rock slope mapping and unstable object inventory together with plots of all monitored objects with actual monitoring results and their safety evaluations. The portal also provides on-line results from 4 automatic data acquisition units installed on other hot spots of NP area.

14.3.4 Remedial Measures

Three groups of remedial measures have been used in accordance with differences in the typology of unstable objects, their actual instability, and levels of risk to inhabited areas, transport routes or tourist trails. *(x) The simple technologies* – which are possible to accomplish by a hand-work, using only technically very simple means. Those works are systematically carried out by the National Park Staff – a special group of alpinists, which is supervised by a geologist *(xx) The most technically, organizationally* (e.g. emergency evacuation of part of a village, medium till long time traffic break off etc.), and, of course, *economically demanding measures* are realized on a commercial platform. An expert team delegated by the National Park Administration and Ministry of Environment during those works supervises specialized geotechnical enterprises. The most dangerous cases are – in accordance with the Emergency Law of CR, treated in collaboration with State Police and Army, and coordinated by the Integrated Rescue Body coming under Ministry of Internal Affairs. In this case, the supervising team has to embodied experts from all the involved entities. *(xxx)* Special, *medium position* is held by a *long-term – tens of years lasting monitoring* of potentially unstable objects, because it is able to substitute the costly and sometimes even nature-unfriendly technical measures for the majority of objects. In this case, monitoring is used ensure, that the rock fall preparation process is still remaining in its medium, long-lasting phase. By revealing a shift from that phase towards the last, short time lasting phase, such monitoring also provides a guaranty that the technically very demanding measures will be limited only to the objects, which high danger state had been rigorously proven by hard data from monitoring.

14.4 Discussion

The locally – according the degree of rock fall risk, spatially differentiated approach of successive survey steps had proven its reliability. Every year since the very beginning of the project in 2002, there had at least occurred one bigger rock fall and several smaller ones within the National Park Territory (Vařilová and Zvelebil 2005b). But none of them had unexpectedly occurred within the areas of special interest – i.e. above settlements and the main tourist trails. In contrary, even from 2003 till 2005, 12 cases of high instability of rock objects had been detected and treated – 8 cases of the simple, 3 cases of the higher, and 1 case of the highest technological demands (Fig. 14.4), in those areas of special interest before they were able to do substantial harm. The detailed inventory maps of unstable rock object have been also used by the local authorities to regulate the building activity within the area of Hřensko Village.

The latest experience from the 2004/2005 winter could be regarded as a very important lesson. On one hand, it has strengthened our hopes in the new, on dynamical systems based analytical methods to timely provide the rock fall early warning even from very short monitoring time series. On the other hand, it has reminded us the possibility of human mistake which is especially dangerous during the survey phase of detailed inventory of unstable rock objects. A medium size rock fall which had unexpectedly occurred from previously surveyed part of slope above a local road (Stemberk 2004) in winter 2005 provided the first negative exception from the above listed statistics of success. Nevertheless, when the unstable/potentially unstable rock object would be correctly fixed and their monitoring started, chance of such mistake could be substantially decreased.

Relatively very short, only a few of months lasting time series from a suspicious rock pillar with the volume of 30 m^3 which endangered a tourist trail, were not possible to interpret by any regular method due to screening of rock mass irreversible deformations by environmentally driven reversible changes of rock mass volume. Using the new method of displacement/displacement and displacement/temperature parallelograms (e.g. Zvelebil et al. in print) those time series were deciphered and unusual ac-

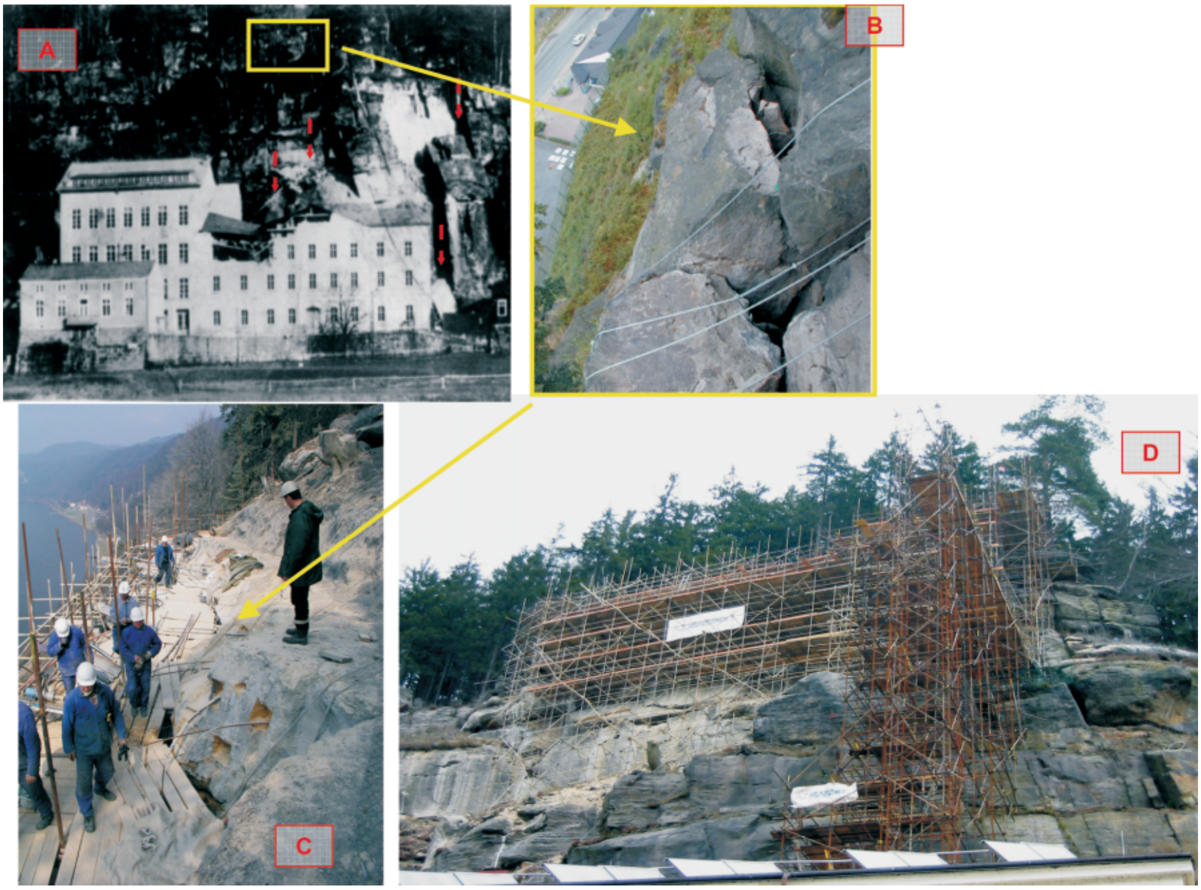

Fig. 14.4. Site of repeated rock fall danger which required technically demanding remedial measures by anchoring in Hřensko Village. **a** Damaged roof and house walls by a 400 m^3 rock fall in 1936. *Yellow box* marks the site of new, detailed photo **b**. **b** Fresh opening of joints by restored preparation activity, of another rock fall in late fall 2002. **c** The same site as on photo **b** under progress of remedial measures. **d** Heavy scaffolding was needed to realize anchoring works during winter 2002/2003

tivity of irreversible deformations shown (Fig. 14.5). Conclusion driven from the latter about high instability of that pillar was then supplemented by a time forecast of rock fall occurrence, which had been given 3 months before the expected collapse event in December 2004 (Zvelebil 2004). The pillar collapsed on 12 March – just in the predicted time window of March 2005, providing an evidence for correctness of our interpretations. Falling rocks hit badly the tourist path bellow, but that path had been closed – in accordance with this stability evaluation, since January (Vařilová and Zvelebil 2005b).

The regional monitoring net has encompassed all known areas of the highest rock fall risks within the area of Bohemian Switzerland National Park but it still remains expanding gradually in accordance with actual results provided by the unstable object inventory, which is now operating in areas with lower degrees of risk. Up to now, there are 227 monitored rock objects with 511 measuring sites on the territory of Bohemian Switzerland NP. The majority of them – 217 objects with 486 sites, are manually measured by portable dilatometer and extensometric tape. Only 4 objects with 25 sites have been equipped by an automated monitoring system with on-line data transport to a remote, central dispatching. When statistics of the older monitoring net, which spreads over the main road between Děčín Town and Czech-Germany boundary in the Labe Canyon is added, one arrives to the total of 327 rock objects with more than 900 sites. The reason for high degree of automation of IS, especially in its time-series processing and evaluation, which should include an expert module to facilitate the every-day practical use of IS, is clearly visible.

14.5 Conclusions

A high-tech, scientifically challenging Integrated System (IS) of effective, but nature-friendly management of rock fall risks on the Bohemian Switzerland NP territory has been under construction since 2002. Its scientific part has been based on holistic approach to integrate knowledge and methods as from various fields of geosciences, as from nonlinear dynamics and dynamical systems theory. Its

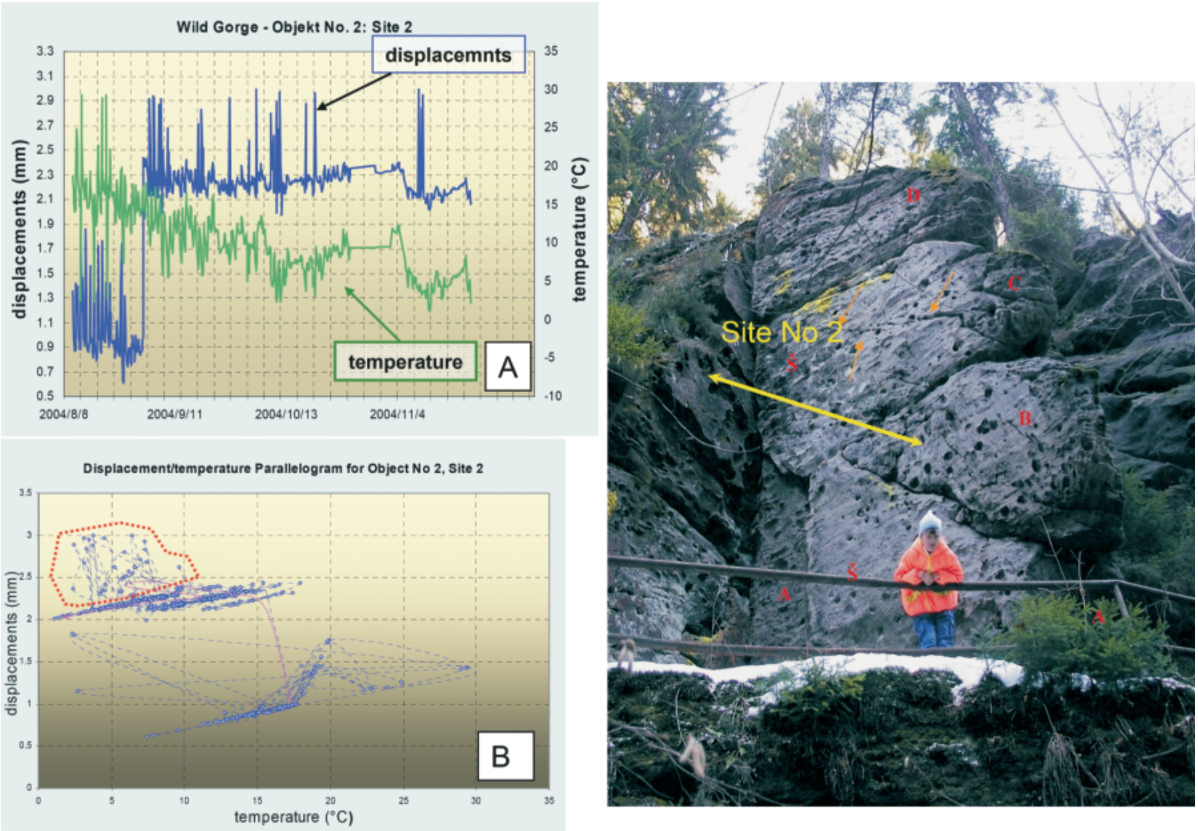

Fig. 14.5. New method of parallelograms was used to decipher short, only 4.5 months lasting time series and to launch a rock fall early warning for a rock pillar just above a tourist trail at the bottom of Wild Gorge of Kamenice River. **a** Current time/displacement plot from the monitoring key site (for its position see photo) is showing only one irreversible jump shortly after the beginning of measurement. **b** Temperature/displacement parallelogram: ordered patterns of diagonal, *from* left to *right* elongated *dot clouds* represent well correlated responses of rocks to temperature changes. In contrary to the current plot, many temperature independent micro slip events are clearly visible as dot groups violating the left-right diagonal patterns. The high density area of the slip events is marked by a *red curve*

technical part has been using progressive tools of Information Technologies (IT) to make information turn-out as rapid as possible. Rapid processing and timely, on-line delivery of relevant, easy-to-understand information to an end-user through an information web portal and cellular phone emergency messages are the highlights of IS.

The high need of maximal automation of monitoring and mainly of monitoring time series evaluation can be clearly seen from present and ever grooving number of monitored rock objects. There are 227 monitored rock objects with 511 measuring sites on the territory of Bohemian Switzerland NP only, and, together with neighbor, out of NP boundary laying area of Labe River Canyon one arrives to the total of 327 rock objects with more than 900 monitored sites.

GIS system techniques are used as to store data, as to improve gain from their synthesis and integrated evaluation, as well as to present the final results in forms of regional rock fall hazard zoning in spatial domain 1 : 10 000, and of detailed rock fall risk zoning in spatial and time domains 1 : 1 000, 1 : 2 000. The latter has also provided basis for exhibition of actual results of monitoring data evaluation for each monitored object.

Systematic monitoring of displacements on cracks within rock mass of potentially unstable objects has a multipurpose use in IS. To ensure its nature-friendly function, monitoring provides as a immediate guaranty as against an unexpected occurrence of a rock fall, as that the technically very demanding remedial measures will be limited only to those rock objects, which high danger state had been rigorously proven by monitoring hard data. The long-term – tens of years lasting monitoring is able to substitute those technical demanding measures for nearly 90% of unstable rock objects, on which the developmental stage of process of rock fall preparation was fixed as the middle, long time – from years up to hundreds of years lasting one

The main qualitative innovation of IS is represented by the implementation of methods from a toolbox of complex dynamical systems. They provide more realistic and mathematically more rigorous grasping of very complex nature of rock slope dynamic. Moreover, due to their numerical nature, they provide also an opportunity to the widest implementation of rough, big-bulk-of-data-at-once-handling force of computers to analyze and evaluate monitoring time series, and to model development of rock slope failure dynamics for advanced, early warning targeting diagnostics and time forecasting. Several successful cases have made those new tools very promising as to diagnose the dynamical shift from that middle to the last, short time lasting phase even from short monitoring time series, as to help to make time forecasts ranging from a few days up to 2 years.

In spite of that partial success, there are two IS modules, which still wait to be substantially enhanced. Methodology of monitoring time series safety evaluation and modeling, which includes data multiple analyzes and syntheses of data from different sources is professionally very demanding. Even a specialist – geologist should be supported by an automated expert system module for the current, practical use of the IS. Besides that, not all of the simple and concise forms of IS outputs for their practical end users have been fixed, yet. Still, the demand for bridging the gap between science, civil protection and general public by a constructive dialogue has not been fulfilled.

Acknowledgments

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