Journal of Nepal Geological Society, 2000, Vol. 22, pp. 85–94

Engineering problems in developing and managing show caves

Arrigo Cigna[1], Franco Cucchi[2], and Paolo Forti[3]
[1]*Società Speleologica Italiana, Frazione Tuffo, I-14023 Cocconato (Asti), Italy*
[2]*Dipartimento di Scienze Geologiche, Ambientali e Marine, Università di Trieste, Italy*
[3]*Istituto Italiano di Speleologia, Università di Bologna, Italy*

ABSTRACT

Show caves play an important role in the socio-economic development of a country. A fast increase of such caves can be attributed to the increasing demand from tourists eager to observe natural features and phenomena. On the other hand, the karst environment is quite vulnerable to changes, and hence the transformation of a natural cave into a show cave must be designed, implemented, and managed with due attention to the problem of environmental protection. For this reason, the contribution of the engineering geology is instrumental. Engineering geology is particularly useful for the following activities.

- Environmental Impact Assessment including choice of the materials to minimise the environmental impact and to optimise the safeguard of tourists and employees;
- Identification and implementation of countermeasures for unstable zones in the cave;
- Design and construction of tourist pathways and other structures;
- Identification of the best light sources and their operation;
- Cave cleaning and maintenance (devices to supply water and to take out sewage, measures to minimise dust, and the problem of maintenance of old show caves); and
- Management of the surface area (planning and managing human activities in the outside area corresponding to the whole intake site for the karst system, as most of them may greatly affect the show cave environment, but, on the other hand, some of them such as parking, ticket office, and toilets are absolutely unavoidable).

In the paper, the main engineering problems related to establishing and managing a show cave are presented together with practical examples from some of the main show caves in Italy and abroad.

INTRODUCTION

All over the world, show caves play an important role in the socio-economic development of a country. An increase of such a role in the developing countries can be envisaged on the basis of a still growing demand of tourism devoted to natural features and phenomena. There are approximately 800 important show caves in the world with a global number of about 170 million visitors per year (Cigna 1999). By assuming a budget per person of US$ 10, the total annual amount of money spent to visit the show caves is about US$ 1.5 billion. The number of the local people directly involved in the show cave business (management and local services) can be estimated around hundred per cave, i.e. about hundred thousand individuals in the world. By taking into account that there are several hundred other persons working indirectly with each person working in the show cave (Cigna and Forti 1989), it can be stated that about 10 million people get their livelihood from the show cave business. Taking into account the visitors of karst parks may further increase this figure. The figure reported above gives an indication on the role played by show caves in the global economy.

On the other hand, the karst environment is one of the most vulnerable, and therefore the transformation of a natural cave into a show cave must be designed, implemented, and managed with a great care. For this reason, the contribution of the engineering geology is instrumental.

In the last decades, engineering geology has been proved to be fundamental in many aspects of managing the show cave. Most important of them are: Environmental Impact Assessment, environmental stability, tourist pathways and basic structures, lighting systems, cave cleaning and restoring, and outside area management. In the following paragraphs, the main engineering problems related to all of these aspects are outlined together with the practical examples from some of the main show caves in Italy and abroad.

CONCEPT OF ENERGY LEVEL AND ENVIRONMENTAL IMPACT ASSESSMENT

The visitor capacity of a cave is defined as the maximum number of visitors acceptable in a time unit under defined conditions that do not imply a permanent modification of a relevant environmental parameter of the cave (Cigna 1989; Cigna and Forti 1989, 1990). This definition is based on the following assumptions:

1. Natural fluctuations of environmental parameters are considered safe for the integrity of the environment itself.
2. If the number of visitors in a cave per unit time is gradually increased, one environmental parameter will exceed the range of its natural fluctuation prior to other parameters. Such a parameter can be defined as a critical factor.
3. The visitor capacity corresponds to the maximum flow of tourists through the cave that changes the critical factor to the limit of its natural fluctuations.
4. The grouping of environmental parameters into major and minor ones is rather arbitrary. If air temperature, carbon dioxide concentration, and water quality are classified as major parameters, the appropriate classification of the other parameters may require detailed study. The significance of the other parameters may vary widely from cave to cave.

Aley (1976) described another important problem in caves, which can actually become exacerbated by the use of carrying capacity number as a management technique. He correctly argued that most show caves have abundant non-renewable resources in their speleothem display. Once damaged, these resources cannot be replaced, at least not in human lifetimes. A cave with one or more highly decorated passages could require a low carrying capacity if the decorations are within human reach of the trail, or within the sphere of influence of human-induced changes that adversely affect the speleothems. As damage is incurred and speleothems are removed, broken, defaced, or tainted, then the passage becomes less pristine. At that point, it can be argued that the carrying capacity has risen because fewer speleothems now remain to be damaged and the quality of the experience has been denigrated. This is contrary to the entire concept of carrying capacity, which dictates that use levels should decline as the resource declines.

Heaton (1986) reviewed the concept of energy level as applied to caves. He classified caves into the three categories: high-energy, moderate-energy, and low-energy levels. High-energy caves experience high-energy events on a regular basis. An example would be those caves that undergo periodic flooding. The strongest forces normally encountered by moderate-energy caves are orders of magnitude lower than those associated with high-energy caves. The most significant forces may be running water, persistent wind, or even the activities of animals. Low-energy caves are again orders of magnitude smaller. Often in these caves the highest energy event may be a falling drop of water.

According to this classification, high-energy passages will be minimally affected by tourist activities because such passages will be rearranged by rockfall or flooding within a year. In moderate-energy passages, which often have the most abundant displays of speleothems, the presence of visitors may have a more lasting effect. During short periods of time, the energy released by tourists can be of the same order of magnitude as that released by natural processes, which normally operate in those caves. This could lead to irreversible damage.

A visit to a low-energy cave may have more serious implications, because in a very short time interval more energy could be released than it had experienced in perhaps a thousand years. The damage caused by one group of visitors may be profound and the speleothems may quickly be destroyed. It is the authors' experience that most tour caves are found to be in the low to moderate energy range, due to the difficulty and great cost of developing and maintaining high-energy tour caves.

The field situation is far more complex than the simplified examples of energy levels given above. A single cave may exhibit examples of all three energy levels when different sections of a given cave are considered. Because, in principle, tourist trails may cross all three energy levels, each area should be regarded separately in a coherent overall management plan. Devising and implementing such a plan would undoubtedly be a complicated and expensive process.

The use of a visitor carrying capacity model (Forssell 1977; Middaugh 1977; Van Cleave 1976) could be modified to 'fit' certain caves that have unique resources. For example, those caves with rare and generally irreplaceable cultural, biological, and/or speleothem resources, and which are easily destroyed merely by the presence of visitors should be managed in a very restrictive manner. The caves belonging to this category would be a few and considered national or international treasures. Two examples are the Lechuguilla Cave in the United States and the Lascaux in France.

Another category could be those caves with rare and significant ecological resources that could be sustained even with visits, provided they have adequate management. An example is the Glowworm resource in the Waitomo Glowworm Cave in New Zealand. The last category would be those caves with minimal cultural, ecological, or speleothem resources. This type of classification is already followed in many of the undeveloped caves on federal government-managed land in the United States.

In many cases, caves with significant resources require permits to enter and limits are put on party size. Also, visits may be restricted to a particular time of year and there may be limits to where one can travel in the cave. These management techniques help to control and direct traffic to minimise damage. They also restrict most damage to the heavily travelled routes and create a distance-decay relationship of impacts as the distance from the trail increases. This relationship generally applies to large show caves where the tourist route is only a small fraction of the entire cave. Thus, the visitor capacity is just one of the several parameters which must be taken into account before transforming a wild cave into a tourist one.

The procedure of Environmental Impact Assessment (EIA) for caves was developed in the last decade (Huppert et al. 1993) and it is now widely applied (Fig. 1a, b). Such an assessment starts with a pre-operational phase to obtain sufficient information on the undisturbed status of a cave to be developed into a show cave. If possible, collection of the main parameters of the cave climate should be done during one year (at least) before the start of any intervention on the cave. Such a collection can be obtained either by spot measurements or, better, by data loggers.

Successively, a programme for its development is established with the scope to optimise the intervention on the cave at the condition that its basic environmental parameters are not irreversibly modified. The last phase of the assessment is focused to assure a feedback through a monitoring network in order to detect any unforeseen differences or anomalies between the project and the effective situation achieved after the cave development.

Once an energy balance of the cave is obtained, the perturbation due to the cave development (lighting, pathways, etc) and the visitors can be evaluated and compared to the natural variation of the parameters. An optimisation of the project is then set up on the basis of the constraints given by the protection of the cave environment and the requirements of the commercial exploitation.

It is convenient to establish an *ad hoc* scientific committee already in the early phase of the cave development in order to insure the best implementation of the results of the monitoring into the project. In addiction, such a scientific committee can play an important role after the cave is open to tourists. In some instances, this scientific committee has played an additional role of co-ordinating scientific researches in the cave. This was the case of the caves of Frasassi (Ancona, Italy) where the committee promoted a large number of studies (Bertolani and Cigna 1994). In addition to this advantage, there is also a direct positive effect on the protection of the cave environment, because when part of a large system is developed for tourism, a control is automatically assured also for the other parts of the cave, which would have been open to everyone if the cave had remained wild (Forti 1996).

ENVIRONMENTAL STABILITY

The deep karst environment is the place of a more-or-less continuous speleogenetic process, which causes a progressive modification in the shape and stability of the cave's passages. This does not signify that caves undergo rapid and profound transformation. In fact, it has been noted that there are many caves formed hundreds of millions of years ago and they can be visited in a safe and sound conditions. Nevertheless, during the planning of a show cave, one of the first issues to be taken into account is the static stability and/or ensuring the safeguard of floors, walls, and ceilings along with all the paths to be opened to the public.

There are at least two elements to be considered with regard to the safety of people within the cave: the stability of the entire cave itself and that of logistic works constructed therein. The stability of the cave itself is usually neglected, as it is assumed that a form with such a slow geostatic evolution has always a good stability. Therefore, no applied geological study or geostatic analysis would be carried out in caves, if not as a method of solving problems created through human activities. The study is very importance for the caves, which are potentially dangerous from the geostatic point of view due sometimes to the poor geotechnical characteristics of the rocks and/or to the presence of discontinuity planes that may transform into potential slip surfaces. This would give a choice for the best position of the trail by leaving out the parts at risk.

It must not be forgotten that the evolution of the cave is extremely slow but, sometimes, it may also be catastrophic with sudden re-adaptation to new conditions of stability. Consequently, a monitoring network should be established in the areas at risk without underestimating any evidence of instability. Recently, during the construction of a new pathway in the Grotta Gigante near Trieste, it became necessary to remove several boulders and flowstones from the overhanging walls, because they became unstable due to the excavations at the foot of the pathway itself. It has not been realised that the calcite crusts could be so weak, being separated by lime and clay layers, and not interconnected. Unfortunately, this removal caused the destruction of some particularly valuable elements from the aesthetic point of view.

The removal of boulders or unstable material in a cave is much more complex than the same operation on roadsides. The material to be moved can be placed on a path ledge, and therefore is not always completely safe, as it may cause a "chain reaction" and affect other interesting scenic forms.

The geotechnical characteristics are not the only ones to be taken into account but also the hydrogeological ones may have some relevance. Recently, an 'exceptional' rain together with a sudden re-opening of the water passage, which had been previously blocked by detritus transported by the flood revealed the danger in some parts of the Grotta di Bossea (Piemonte), where the pathway was suddenly flooded. Therefore, it is necessary to install alarm sensors and control the water flow, to avoid such dangerous events.

Tourist pathways and basic structures

The safety of some structures (pathways, stairs, hand rails, electrical networks, etc.) are often left to the common sense of the workmen who are not always aware of the characteristics of the underground environment. They are usually satisfied by the normal compliance with the legal requirements. In so doing, they neglect that materials wear out much faster in underground conditions than in the open air. Under the high humidity conditions, there are more chances to slip and fall on excessively steep slopes, on inclined steps, or on a group of steps of differing heights.

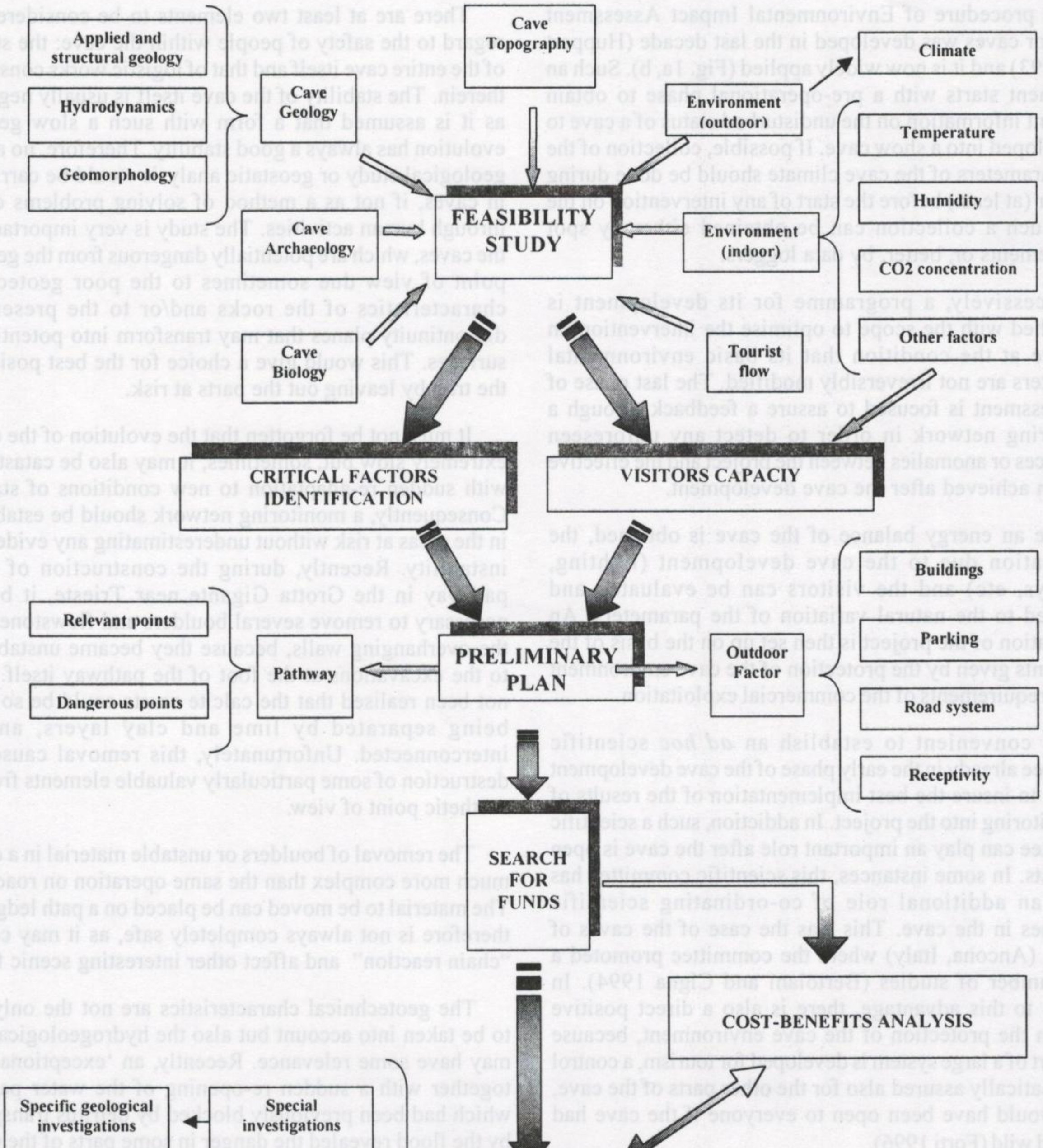

Fig. 1a: Environmental Impact Assessment for the development of a tourist cave (contd. in Fig. 1b)

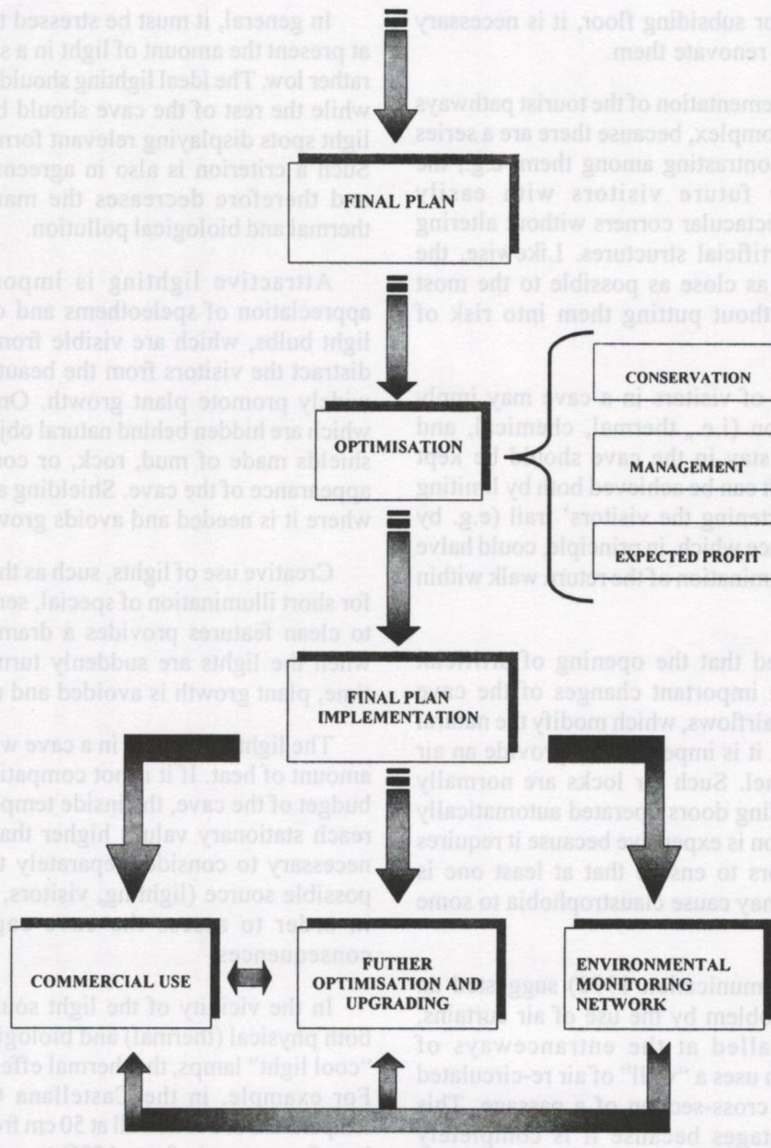

Fig. 1b: Environmental Impact Assessment for the development of a tourist cave (Contd. from Fig. 1a)

It is of little importance that substantially the requirements of the law have been complied with. Uneven flooring or a surface that collects dust and sediments become extremely dangerous in a cave.

Many kinds of material are currently available in the market today and it would be enough to use a little initiative to find the suitable material for this purpose. It would not take much, for example, to transform a simple handrail into a water pipe: it is possible to carry water for cleaning purposes or for other reasons (to refill a small lake or to feed a stream) without additional pipe requirements and relative camouflage. At the same time, it is quite easy to have non-slippery floor, so that visitors would not be forced to watch their own head while looking around. The support material should be in stainless steel and the gangways in a finely woven grid (stiletto heels still exist), the concrete protected by Plexiglas (where necessary), etc. However, even after a cave complies with safety requirements, the problem of stability must be constantly controlled for all the period that the tourist cave is in function. In fact, the speleogenetic process does not stop because the cave is open to the public, and therefore it is necessary that the cave monitored in order to foresee danger.

Such an investigation has to be carried out very carefully in order to avoid unjustified countermeasures. For example, a few years ago, in the Grotta di Frasassi, in the Marche District, Italy, a couple of pillars along the tourist trails appeared cracked and, apparently, it was a sign of a relevant risk for the visitors. However, a closer examination and the installation of a number of gauges confirmed that such pillars were no longer supporting any load. In the caves, where impressive and fascinating stalagmite column have been disturbed by earthquake or subsiding floor, it is necessary to set up interventions to renovate them.

The planning and implementation of the tourist pathways inside a cave are always complex, because there are a series of problems sometimes contrasting among them, e.g., the opportunity to supply future visitors with easily approachable but safe spectacular corners without altering the cave with a heavy artificial structures. Likewise, the visitors should approach as close as possible to the most beautiful formations, without putting them into risk of vandalism or destruction.

Because the presence of visitors in a cave may imply various types of pollution (i.e., thermal, chemical, and biological), the visitors' stay in the cave should be kept within a limit. Such a result can be achieved both by limiting their number and by shortening the visitors' trail (e.g. by opening an artificial entrance which, in principle, could halve the time of a visit by the elimination of the return walk within the cave).

It must be emphasised that the opening of artificial entrances could result in important changes of the cave microclimate by inducing airflows, which modify the natural air circulation. Therefore, it is imperative to provide an air lock in the artificial tunnel. Such air locks are normally obtained by installing sliding doors operated automatically by a photocell. This solution is expensive because it requires at least two or three doors to ensure that at least one is closed at any time and it may cause claustrophobia to some persons.

Gurnee (personal communication 1990) suggested an elegant solution to the problem by the use of air curtains, which are usually installed at the entranceways of warehouses. An air curtain uses a "wall" of air re-circulated by fans through a whole cross-section of a passage. This system has many advantages because it is completely invisible and non-obstructing to tourists. It also seals itself around people passing through it, and reduces the infiltration of dust and spores carried along by visitors.

A couple of air curtains installed one after the other and operated alternatively every other day assure their operating capacity so that, in case of a failure, one air curtain is surely available until the other one is fixed. In addition, the risk of failure is reduced with respect to a mechanical door because the only part in movement is the fan, which is a rather robust and reliable apparatus.

Lighting systems

The design and implementation of a lighting system is surely one of the most important issues for the development of a show cave. Both the aesthetical quality and the cost of management are greatly depending upon the lighting system. In addition, it contributes also to the thermal and biological pollution of the cave.

In general, it must be stressed that, contrary to the past, at present the amount of light in a show cave should be kept rather low. The ideal lighting should show the tourist pathway while the rest of the cave should be left half-lit with some light spots displaying relevant formations or other features. Such a criterion is also in agreement with energy saving, and therefore decreases the management cost and the thermal and biological pollution.

Attractive lighting is important for the visitor's appreciation of speleothems and other cave features. The light bulbs, which are visible from the trail, are eyesores, distract the visitors from the beauty of the cave, and more widely promote plant growth. On the other hand, lights, which are hidden behind natural objects or natural-appearing shields made of mud, rock, or concrete, enhance the true appearance of the cave. Shielding also directs the light only where it is needed and avoids growth of algae.

Creative use of lights, such as the installation of switches for short illumination of special, sensitive, or otherwise hard to clean features provides a dramatic display for visitors when the lights are suddenly turned on and, at the same time, plant growth is avoided and energy is saved.

The lighting system in a cave will contribute to a certain amount of heat. If it is not compatible with the total energy budget of the cave, the inside temperature will increase and reach stationary values higher than the natural ones. It is necessary to consider separately the contribution of each possible source (lighting, visitors, and other heat sources) in order to assess the cave capacity for irreversible consequences.

In the vicinity of the light sources, the effects may be both physical (thermal) and biological. When lamps are not "cool light" lamps, the thermal effect can be very important. For example, in the Castellana Caves, South Italy, the temperature of a rock wall at 50 cm from a 1 kW lamp increased in a few seconds from 15°C to more than 25°C while the relative humidity decreased from 95–100% to 55–60%, and a strong upward air current was established. As a consequence of these effects (which are rather peculiar), aragonite flower grew on a calcite stalagmite (Forti 1980).

In the biological domain, a rather widespread effect is the proliferation of algae and mosses near the light sources. These organisms not only have an aesthetic negative influence on the cave environment, but can also set up a corrosion of speleothems by biochemical processes. Incandescent lamps are still widely used and have an emission spectrum rather large covering many absorption bands typical of vegetal organisms (Imprescia 1983).

The use of "cool light" lamps and, in any case, the positioning of lamps at some distance from the cave walls would reduce the local thermal pollution or, at least, some local consequences (Caumartin 1993). To keep the amount of input energy as low as possible, the lighting system could be divided into many sections in order to have as few lamps as possible turned on at the same time.

The growth of algae and mosses in the proximity of light sources can be greatly reduced or entirely avoided by the use of special vapour discharge lamps which have a light emission limited to some narrow bands not useful for the physiological processes of plants (Imprescia 1983).

Apart from this, any decision about the type, number, and power of the light sources and their subdivision into independent sections is a function of the number of visitors, their flow rate, and the hours during which the light must be switched on.

In a cave like that of Frasassi (which is visited yearly by some hundreds of thousands of tourists, with a peak of up to 10,000 persons per day in the high season) the management of the different sections of the lighting system has to be computerised in order to optimise the results. Light sources, which are switched on for rather long time intervals may consist of discharge lamps (which require a pre-heating time) while the light sources which are frequently switched on and off must be obtained with high efficiency incandescent lamps which do not require any pre-heating.

On the other hand, in caves with a rather low flow rate of visitors, as the Grotta di Onferno (Emilia-Romagna, Italy) with 25,000 tourists per year, the different sections of the lighting system may be easily switched on by sensors along the tourist trail.

Cave cleaning and restoration

The large number of tourists visiting a cave, as an undeniable consequence, carries a certain amount of dust mostly along the tourist trail, but not only. The most noticeable is the mud deposited by the visitors' shoes, which stain the cave and may turn the pathways into unsafe conditions. This is the reason why in every show cave frequent periodic cleaning must be carried out along the pathways. Such cleaning may be rather difficult if the necessary facilities and, first of all water, are not already available.

As it was reported above, the problem of distribution of water in the Grotta di Frasassi was easily solved by the use of handrails (in stainless steel) as a pipe provided with taps at regular intervals along the pathways. Such a solution was also rather cheap because the stainless steel used for the handrails avoided both corrosion and environmental pollution, and the installation of another pipe system to supply water. The discharge of sewage outside the cave was made through a conduit (plastic material) buried in the floor of the pathway.

However, the mud is not the only kind of grime that accumulates in a cave following the tourists' visits. The biological pollution contributed by the visitors is also due to the "cloud" of spores and bacteria they carry along. The consequence of a biological pollution is not limited only to the growth of mosses and plants in the vicinity of lamps. According to Cser and Gadoros (1988), some excentrics could be originated by aerosols. The increase of condensation nuclei due to spores and droplets in the breath of visitors may modify the concentration of aerosols responsible for the helictite growth with an enhanced transformation of excentrics into coralloid formations, as it was observed in some commercial caves.

Another form of pollution is introduced by tourists as dust (Michie 1996). Hairs, dry-flaking skin, and dust from shoes and lint from clothing compose such a dust. In Carlsbad Cavern, USA, the average yearly rate of long-term lint accumulation in the cave was estimated at 2 kg/year (Jablonsky 1990). In the Ngilgi Cave, Western Australia, a deposition rate of 8.3×10^{-3}g m^{-2} d^{-1} was measured (Michie 1997). It is evident that this kind of pollution may result in a threat to show caves. According to Michie (1997) if the use of the cave causes dust deposition that exceeds a threshold of 0.7% in a given time period, then it should be considered to protect the cave by constructing pathways that enable management of the dust problem, e.g. by washing the pathway and a suitable removal of the wastewater into a sewage system that is drained outside the cave.

The chemical pollution originated by visitors is mainly due to the emission of carbon dioxide. Any increase in the carbon dioxide concentration might affect, in principle, the chemical equilibria of the cave formations. Such effects are, of course, much more important in low- and moderate-energy caves. Villar et al. (1984, 1985) reported seasonal variations of some chemical parameters (bicarbonate concentrations, dry residue, and pH) of percolating waters in the Altamira Cave. But they did not observe any permanent changes in a longer period. In some special case, like that of Grotta Bianca inside the Castellana Cave Italy, the increase of CO_2 concentration is threatening speleothems, and sometimes it also affects the visitor's health. The normal situation may be recovered successfully by installing a simple system consisting of a fan filtering the air through an absorber (with $NaOH$ or K_2O_2). Such a system could be fully automatic being switched on by a sensor when the concentration of the carbon dioxide in the atmosphere is higher than a predetermined value. The absorber must be changed when exhausted and the wastes must be removed from the cave to avoid any further pollution.

Many principles of the environmental protection were not considered up to few decades ago, and therefore, some show caves have been designed by employing techniques and materials, which may constitute harm to the cave environment and/or to the visitors. Thus, one of the most relevant applications of engineering geology is the design for renovations of old show caves.

The situations when we are most frequently called in to intervene are - the demolition and/or substitution of parts of old pathways, the replacement of the electric plant with a new distribution of lamps following the criteria briefly reported above, the substitution of the original material (generally cement, iron, and wood), with others more suitable to the cave environment and less noticeable as mentioned in the relative paragraph. When these operations are planned, firstly they must be put in the right perspective. In particular, any overburden has to be avoided (e.g. excessively wide pathways and too high electrical power). Thus the cost of management is kept as low as reasonable without any excessive environmental impact.

There is another fundamental aspect, of course, to bring back a show cave to a more natural condition, which includes the cleaning of parts once occupied by pathways no longer in places, removal of biological encrustations, the veil of soot and disfiguring writing on the formations and walls. Different methods must be applied in order to mitigate each one of these disfigurements. It is also necessary to adjust the type of operation depending on where the cleaning has to take place. It is evident that a too strong cleaning action, as in the case of a delicate speleothem, instead of an improvement, could cause the complete destruction of it. For this purpose, some cleaning techniques are summarised in Table 1 (Veni 1997).

The maintenance of broken speleothems (during the planning of a show cave or those caused by successive vandalism) is another part of the return to a more natural condition, which calls for sophisticated materials and techniques. It is then possible not only to reassemble the fragments as "natural" as possible but also the partial reconstruction of it when some parts are lost or missing through actions by vandals, and lastly, in a much longer period, the natural evolution of the repaired concretion (Veni 1997).

A last aspect of the more natural conservation is that of maintenance or re-establishment of the original water flow before the transformation into a show cave. In fact, the tourists' presence means a diminution of water flow basically due to the increase rate of evaporation, a consequence of a higher rate of airflow and, possibly, a temperature rise, but also from the waterproofing of the feeding basin. This is the reason why some small ponds, originally full of water, have dried up completely as well as many stalactites or flowstones. It certainly causes a decrease of the general beauty value (loss of vivid colours and the brilliant appearance of the formations) but also, and above all, the decay of the speleothem itself that sometimes becomes corroded due to condensation.

It is not always possible to restore everything exactly to the original conditions before the adaptation of the show cave, and therefore an artificial water system is necessary, which can contribute to keep the local water at the same level as it was before. The solution applied in the Grotta di Frasassi for the cleaning water supply for the pathways resulted to be quite convenient for this purpose.

Management of the surface area

Generally, there is the problem of compatible management of the surface area corresponding to the whole intake area

Table 1: Summary of techniques for cleaning speleothems (after Veni 1997)

Pollutant	Large/strong speleothems	Small/delicate speleothem
Rocks and gravels	Shovel into buckets. Then hand scoop. Then follow methods for sand and clay	Hand pick and scoop into buckets, use tweezers for hard-to-reach material. Then follow methods for sand and clay
Sand and Clay	Sweep as much as possible. Then wash with pressurized water	Wash with low to moderately pressurized water
Carbide	Scoop with gloved hands, sweep with soft brush, and wash with moderately pressurized water	Sweep with soft brush, and wash with low to moderately pressurized water
Soot	Wash with moderately pressurized water; scrub with soft brush if needed	Wash with low to moderately pressurized water
Lint	Wipe and sweep with duster and soft paint brush	Sweep with soft paint brush, pick with tweezers, and use mist or steam where hard to hand-clean or reach
Algae, plant and moss	Spray with bleach; wait 3-5 days and rinse thoroughly	Spray with bleach; wait 3-5 days and rinse thoroughly
Paint	Clean with CO_2 –powdered washer or spray with H_2SO_4; scrub with soft brush, and rinse thoroughly	Clean with CO_2 – powdered washer
Concrete and Weld	Hammer with a small chisel or pick to remove poorly attached pieces or poorly attached portions of well attached pieces. Then apply H_2SO_4 the weaken the bond and continue picking. Rinse thoroughly	Apply H_2SO_4 and pick carefully. Rinse thoroughly
Carbonate covered stains	Apply H_2SO_4 and scrub with soft brush to remove thin calcite layer and stain. Rinse thoroughly. Do not disturb if thickly covered with calcite	Do not disturb

for the karst system to which the show cave belongs. In the past, also the cave management paid little or no attention to the environment outside the cave. Such behaviour resulted sometimes in a serious damage to the show cave itself.

In the Castellana Caves (Puglia, Italy), at the beginning of the 1980s, the local municipality built a network to supply sweet water to the farms above the caves without providing, at the same time, a corresponding sewage system. Consequently, in a short time the caves were affected by a rather noteworthy organic pollution. The problem was solved by providing a farm sewage system (Forti and Cigna 1983). But the consequences on the cave environment required a longer time to disappear. The effluents from a few houses located above the Grotta Gigante (Trieste, Italy) have produced heavy local percolation that still corrodes some speleothems. Now it is realised that a special care has to be taken in planning and managing human activities in the whole intake area, because most of them may greatly affect the safety of show caves.

When planning and implementing a new show cave, it is absolutely necessary to install facilities as hotels, restaurants, ticket office, selling points, etc. outside the absorbent area to avoid changes in its hydrologic characteristics. In any case, this planning must be carried on very carefully. The ideal solution would be the installation of all the facilities outside the karst area, as it happened in the case of the Grotta di Frasassi, where the car park, the booking office, toilets and souvenir shops have all been situated on a river terrace about 500 m away from the karst system. In most cases, this solution is not possible, and therefore it is necessary to find out other solutions to minimise the impact on the cave ecosystem (e.g. by placing the facilities downstream of the cave itself in order to avoid pollution within the cave). When the facilities must be installed above the cave (for some special local reasons), great care must be paid by applying absolutely safe technologies and materials.

Apart from rain, the dispersion of all water (from sewage, technical services, etc.) must always be avoided. Such waters must be brought outside the karst area through a sewage system. Due to the heterogeneous drainage of the karst environment and the high velocity flow that characterises the infiltration, it is not possible to adopt cesspits or to disperse wastewater through irrigation because the risk of cave pollution would be too high. In order to respect the natural infiltration of water, it is necessary to avoid sealing of large surfaces and not to alter the water flow in the cave. Therefore, concrete and asphalt must be avoided in car parking areas. Other materials as perforated pavements based on a filter layer, which allows the percolation of rainwater into the cave and keep any release (used oil, petrol, etc.) from the cars, should be preferred. A similar type of rehabilitation of more natural conditions was made in the last years in a large car park of the Grotta di Castellana, and the results have been very positive with the reactivation of many speleothems along the tourist pathway in the cave that had been completely dried since tens of years.

CONCLUSIONS

Show caves are the source of economic wealth resource all over the world, but the income from them largely depends on how they are planned and managed. In fact, a wrong design and a bad management may result in a number of events, which could cause dramatic consequences on the show caves, on the number of the visitors and, in limited cases, the total destruction of such a resource.

Many of the principal problems, which characterise the design, and management of a show cave fall in the field of engineering geology. Unfortunately, at present the only time these problems are momentarily solved is when a specific economic interest is involved and without a due consideration to any further existence of these problems in the future. The damage to the cave environment due to a bad management may appear only after some tens of years. Therefore, it is very important that an engineering geologist is included in the management staff of each show cave with the responsibility of operative choices in relation with all what concerns the modification of and safeguarding the underground environment in every way.

REFERENCES

Aley, T., 1976, Caves, cows and carrying capacity. National Cave Management Proceedings, 1975, 6–10 October 1975, Speleobooks, Albuquerque, pp. 70–71.

Bertolani, M. and Cigna, A. A., 1994, Activity of the Scientific Commission of "Grotta Grande del Vento" (Genga, Ancona, Central Italy). Int. Jour. Sp., v. 23(1–2), pp. 51–60.

Caumartin, V., 1993, *Évolution des idées en matière de corrosion et de conservation du milieu souterrain.* Cent ans de spéléologie française, Féd. Fr. Spél., Spelunca Mémoire, Paris, No. 17, pp. 273–275.

Cigna, A. A., 1989, *La capacità ricettiva delle grotte turistiche quale parametro per la salvaguardia dell'ambiente sotterraneo - Il caso delle Grotte di Castellana.* Atti XV Congr. Naz. Speleol., Gruppo Puglia Grotte - Amm. Comunale Castellana Grotte, pp. 999–1012.

Cigna, A. A., 1999, *Environmental Protection and Management of Show caves.* The Case of Italy. In press.

Cigna, A. A. and Forti, P., 1989, The environmental impact assessment of a tourist cave. Cave Tourism . Proc. Int. Symp. 17Oth Anniv. Postojnska Jama, Postojna, Nov. 10–12, 1988. Centre Scient. Res. SAZU & Postojnska Jama Tourist and Hotel Organiz, pp. 29–38.

Cigna, A. A. and Forti, P., 1990, La V.I.A. delle grotte turistiche. The E.I.A. of a tourist cave. VIA, l' Arca Edizioni, Milano, v. 4(16), pp. 42–53.

Cser, F. and Gadoros, M., 1988, The role of aerosols in cave deposition. Proc. Int. Symp. on Phys. Chem. and Hydr. Research of Karst, Kosice, 10–15 May 1988, Slovenska Speleologicka Spolocnosf, Liptovsky Mikulas, pp. 25–34.

Forssell, S., 1977, The concept of carrying capacity and how it relates to caves. National Cave Management Proceedings 1976, 26–29 October 1976, Speleobooks, Albuquerque, pp. 1–5.

Forti, P., 1980, *Formazione di aragonite nella Grotta di Castellana: un esempio della modificazione indotta dalla turisticizzazione.* Grotte d'Italia, v. 4(8), pp. 1–10.

Forti, P., 1996, Turisticizzazione e tutela dell'ambiente ipogeo: due aspetti non contrastanti. In: Cigna A. A. (Ed.) - *BOSSEA MCMXCV.* Proc. "Show Caves and Environmental Monitoring" Symp. Int., Frabosa Soprana (Cuneo) 24–27/III/1995, pp. 49–56.

Forti, P. and Cigna, A. A., 1983, Relazione della Commissione Tecnico-Scientifica per lo studio di alcuni fenomeni di infiltrazione nelle Grotte di Castellana. Interim Report, Amministrazione Provinciale di Bari, 35 p.

Heaton, T., 1986, *Caves. A Tremendous Range in Energy Environments on Earth.* National Speleological Society News, August, pp. 301–304.

Huppert, G., Burri, E., Forti, P., and Cigna, A., 1993, *Effect of Tourism Development on Caves and Karst.* in: P.W. Williams (Ed.) - Karst Terrains, Environmental Changes and Human Impact. Catena Supplement 25, pp. 251–268.

Imprescia, U., 1983, Considerazioni teoriche sulla radiazione emessa da vari tipi di lampade in relazione alla formazione alla crescita di alghe e muschi sulle pareti illuminate di grotte turistiche. Grotte d'Italia, v. 4(11), pp. 93–101.

Jablonsky, P., 1990, Lint is not limited to belly buttons alone. National Speleological Society News, v. 48(5), pp. 117–119.

Michie, N., 1996, Investigation of visitors impacts at Jenolan Caves (N.S.W., Australia). In: Cigna A. A. (Ed.)- *BOSSEA MCMXCV*. Proc. "Show Caves and Environmental Monitoring" Symp. Int., Frabosa Soprana (Cuneo) 24–27/III/1995, pp. 235–239.

Michie, N., 1997, The threat to caves of the human dust sources. Proc. 12° Int. Congr. Spel. LaChaux-de-Fonds, Switzerland, Symposium 5: Applied Speleology, 5, pp. 43–46.

Middaugh, G., 1977, Practical experiences with carrying capacity. National Cave Management Proceedings, 1976, 26–29 October 1976, Speleobooks, Albuquerque, pp. 6–8.

Van Cleave, P., 1976, *Some thoughts on the carrying capacities of developed caves.* National Cave Management Proceedings 1975, 6–10 October 1975, Speleobooks, Albuquerque, pp. 73–74.

Veni, G., 1997, *Speleothems: Preservation, Display, and Restoration.* In Hill C. A. & Forti P. "Cave minerals of the World", Nat. Sp. Soc., pp. 301–309.

Villar, E., Bonet, A., Diaz-Caneja, B., Fernandez, P. L., Gutierrez, I, Quindos, L. S., Solana, J. R., and Soto, J., 1984, Ambient temperature variations in the hall of paintings of Altamira cave due to the presence of visitors. Cave Science, Trans. British Cave Research Association, v. 11(2), July, pp. 99–104.

Villar, E., Bonet, A., Diaz-Caneja, B., Fernandez, P. L., Gutierrez I, Quindos, L. S., Solana, J. R., and Soto, J., 1985, Natural evolution of percolation water in Altamira cave. Cave Science, Trans. British Cave Research Association, v. 12(1), March, pp. 21–24.