1/2007, 50th year
Losses and loss prevention

Schadenspiegel
Special feature issue
Risk factor of earth

Münchener Rück
Munich Re Group

Risk factor of earth
Our habitat in motion

Dear Reader,

Driving tunnels, drilling for crude oil and natural gas, and erecting dams – civil engineering projects involve immense risks.

In this third special feature issue, our authors report on major losses in tunnelling projects, an uncontrolled escape of gas in a production well, a landslide that caused massive damage on the construction site of a hydropower station, and homes on a new housing estate that were built on peat.

We also show how complex and painstaking remediation can be on an old gasworks site – where soil and groundwater pollution is extreme.

In the special section beginning on page 24, we feature a number of topics presented by our Geo Risks Research team. Our review of earthquakes between 1994 and 2006 continues one of our Schadenspiegel traditions. The article on volcanic activity summarises the latest findings on the risk of eruptions.

This issue also contains our review of major losses and natural catastrophes in 2006.

Your Schadenspiegel team

Enclosed with the magazine are *Schadenspiegel 50 years* and No. 14 (new edition) in our series Technology for underwriters, which deals with gas turbines and combined cycle power stations.

In order to prevent or at least minimise the size of losses occurring during tunnelling projects, professional risk management measures are necessary.
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Earthquake catastrophes 1994–2006: This follows on from the second review that appeared in the special issue of Schadenspiegel in 1994.
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2.5 million tonnes of copper and gold ore and waste material slid over 450 m down an open-pit slope.
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In focus

The future of tunnelling

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Special topic: Earth – When the forces of nature become a danger

Individual losses

12 February 2007, São Paulo, Brazil: The launching shaft and parts of the running tunnels beyond collapsed during work on a new underground station.

Risk factor of earth

The dangers arising from the subsoil are manifold. Large masses of earth move in natural ways – or as a result of human activity.

Munich Re assesses and evaluates the risks involved – that is our business.

The future of tunnelling

Risk management for tunnelling projects

Catastrophic accidents in the course of tunnelling projects have been exerting a substantial strain on the international insurance industry since the 1990s. Major losses have led to contractors' all risks insurance for tunnelling projects becoming less and less attractive. The Code of Practice for Risk Management of Tunnel Works, which Munich Re played a major role in developing, aims to minimise the frequency and size of claims in tunnel works.

Author
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São Paulo, Brazil, 12 January 2007: The launching shaft and parts of the running tunnels beyond it at the future subway station Pinheiros collapse during construction work on underground railway line 4, increasing the diameter of the shaft from 42 to 80 m. According to press reports, seven people are killed. No official statement has yet been made on the cause of loss – an investigating committee is conducting an inquiry.

Since the early 1990s, no other area of the construction industry has been as adversely affected by major losses as tunnelling. Besides property losses often in the two-digit million range, third-party liability losses have also been high, and numerous people have lost their lives. The international insurance industry has made payments exceeding US$ 600m for large losses (table 1, page 7).

A variety of causes were responsible for the losses. Numerous collapses were attributable to instability of the ground. Some tunnels were damaged by floods or earthquakes while others were ravaged by fire in the construction phase. Many losses could have been prevented or at least mitigated if professional risk management concepts had been applied. It was thus a logical step for insurers and representatives of the building industry to jointly develop the international version of the Code of Practice for Risk Management of Tunnel Works in 2005. The aim was to introduce and implement sophisticated risk management measures in each project phase in order to avert loss events or minimise their effects.

A review of selected major losses

Heathrow Express Link, London, UK, 1994

The Heathrow Express Link connects central London and Heathrow Airport. The running tunnels were driven with tunnel-boring machines (TBMs) whilst the two stations at the airport were to be built using the New Austrian Tunnelling Method, which involves the application of shotcrete. A number of trial tunnels had been driven successfully and a few tunnel sections subsequently constructed without any problems when, on 21 October 1994, disaster struck. At first, cracks were discovered in the shotcrete lining of one of the three headings, followed by large-scale concrete spalling and subsidence craters on the surface. These problems gradually spread to the other two headings. Finally, all three tunnels caved in one after the other, taking several buildings with them.

21 October 1994, London, UK: There was considerable surface subsidence in three of the headings for the Heathrow Express Link, finally leading to the tunnels caving in.

22 January 2000, Taegu, South Korea: Following the failure of a diaphragm wall, part of an underground station excavation pit caved in. The consequences? A whole section of road gave way and cracks formed in buildings.

Bolu tunnel, Turkey, 1999

Construction work on the Bolu tunnel forming part of the Anatolian motorway was already far advanced when, on 12 November 1999, the area around the town of Düzce (northwest of Bolu) was shaken by an earthquake. It had a magnitude of 7.0 on the Richter Scale and was particularly notable for its unusually high horizontal accelerations.

Besides damaging a motorway bridge section, the quake mainly affected the tunnel named after the city of Bolu. This tunnel was being driven using the New Austrian Tunnelling Method and was in a known fault zone. Although the tunnel had resisted a previous earthquake in August 1999 (100 km west of Bolu), the November quake resulted in a longish section collapsing. The tunnel had been designed to withstand the earthquake strains encountered up to that time but could not cope with the enormous horizontal accelerations.

Taegu underground, South Korea, 2000

A serious accident occurred on 22 January 2000 during the construction of an underground line in Taegu. Following the failure of a diaphragm wall, part of a station excavation pit caved in. The debris buried a local bus: three passengers were killed and the driver was seriously injured. There was considerable damage to neighbouring buildings.

The accident was found to have been caused by a load case that had not been considered in the design phase and was due to unforeseen soil conditions. Large variations in the water table set in motion the previously unexplored gravel and sand banks, triggering the load case which exceeded the design strength of the diaphragm wall.

Tseung Kwan O underground line, Hong Kong, 2001

The Tseung Kwan O line is an extension of the Hong Kong underground network. The tunnels were already complete and the electromechanical work in the underground stations and tunnel tubes far advanced when the region was struck by a severe typhoon. Besides causing torrential rain and devastating winds, it also generated a flood wave that reached the coast on the morning of 6 July 2001.

The roof of the running tunnel between the stations Hang Hau and Tseung Kwan O had an opening for transporting materials into the tunnel tubes. Although the opening was surrounded by a concrete wall to prevent water from entering, it was overcome by the masses of water and the construction site was flooded. As there were no cross-bulkheads, 75% of the new underground line was inundated. The main damage was to the electromechanical equipment such as switchgears, transformer stations, cabling, signalling equipment, and the platform screen doors, escalators, and lifts.

Socatop tunnel, Paris, France, 2002

The Socatop project (Société de Construction de l'Autoroute de Traversée de l'Ouest Parisien) is part of the extension work on the A 86. Its main section is a tunnel with a diameter of 11 m, driven using a mix-shield TBM. The tunnel accommodates two decks each with three lanes of traffic and air extraction and ventilation systems in the crown and invert areas. One of the special features of construction was that the lower carriageway slabs were immediately laid by a travelling formwork running 600 m behind the TBM. Material was taken to the TBM by service trains running under the lower carriageway slabs in the invert area.

On 5 March 2002, one of these trains was on its way to the working face when it caught fire. The tank of the diesel locomotive was soon engulfed in flames, with the result that the train was automatically stopped. The crew attempted to extinguish the fire but could not prevent it from spreading to the spoil conveyor and the ventilation duct, the travelling formwork, and the tunnel's concrete lining. The dense smoke and intense heat blocked the way back to the portal, forcing the workers to take refuge in the TBM's compressed-air chamber. The TBM itself was not damaged by the fire, as it was protected by a sprinkler system at the end of the back-up train.

Shanghai underground's Pearl Line, People's Republic of China, 2003

The central element of Shanghai underground's new line 4 is the tunnel that takes it below the Huangpu River on the way from the economic centre of Pudong towards the city centre. The two parallel tunnel tubes had already been driven using earth pressure balance TBMs when a disaster occurred during the construction of an emergency cross passage below the river in the vicinity of the river bank. Shortly before the breakthrough of the cross passage at a depth of approx. 35 m, there was a massive inrush of material and water, which the miners at the face were unable to control. Although they managed to get to safety, the surface subsided over a large area, seriously affecting neighbouring buildings. A number of high-rise office blocks were severely damaged, others collapsed altogether or had to be demolished because the risk of collapse was too great. A dyke was also badly damaged. For a time, there was a threat of flooding, as the Huangpu River runs very

5 March 2002, Paris, France: Major operation for fire and rescue services in the Socatop Tunnel – a back-up train burst into flames and set fire to machinery and installations (including the ventilation duct).

1 July 2003, Shanghai, People's Republic of China: Subsidences had a devastating effect on buildings after a massive influx of material and water into a cross passage under the Huangpu River.

20 April 2004, Singapore: A retaining wall for the Circle Line collapsed, resulting in severe damage to the six-lane Nicoll Highway directly beside it.

high at that particular time of year. After the ground gave way, the tunnel tubes subsided a few metres and were flooded; the tunnel lining was fractured. The loss was found to have been caused by failure of the ground-freezing unit that had been installed to protect the excavation work for the cross passage.

Circle Line, Singapore, 2004

Contract 824 of the Circle Line in Singapore consisted of running tunnels to be driven by earth pressure balance TBMs and station structures and running tunnels to be built using the cut-and-cover method. The retaining walls of the excavation pits, 40 m deep in some parts, were formed by diaphragm walls and nine levels of horizontal struts. A jet-grouted base slab served as the sealing blanket.

On 20 April 2004, a construction pit was being excavated directly beside the six-lane Nicoll Highway when there was a disastrous collapse. The excavation pit, which was about 35 m deep at the time, collapsed along a length of over 100 m. Four construction workers were killed, the highway collapsed and had to be closed for several months while the damage was being repaired.

A number of causes were identified: use of an inappropriate soil simulation model which over-estimated the soil strength at the accident site and underestimated the forces on the retaining walls within the excavation; an error in the design of the strut-waler support system with the connections being under-designed; and deviations in actual construction, which further aggravated the under-designed conditions.

Orange Line, Kaohsiung, Taiwan, 2005

A two-line underground system is being built in Kaohsiung. Under Contract O2 of the Orange Line, station structures and running tunnels had already been completed and only a cross passage with a pump sump at its lowest point (approx. 40 m) still had to be constructed. There were only a few centimetres still to be excavated when, on 5 December 2005, there was a massive inflow of water and huge amounts of sand. In spite of the workers' rescue attempts, the cross passage and a large section of the running tunnel caved in. The collapse resulted in considerable subsidence and structural damage in a road tunnel above. The loss was caused by defective jet-grouting of the ground in the immediate surroundings of the pump sump.

Code of Practice for Risk Management of Tunnel Works

The international version of the code of practice is based on the Joint Code of Practice for Risk Management of Tunnel Works in the UK, which was launched in London on 24 September 2003 as a combined effort of the UK insurance and tunnelling industries. Originally conceived for the UK market only, it was further developed by members of the International Tunnelling Insurance Group (ITIG) for the tunnelling market worldwide and introduced to the specialist community in April 2006 at the annual conference of the International Tunnelling Association (ITA). Munich Re produced a German version of the international code of practice for use in German-speaking markets, followed by Spanish and Chinese versions. A French version is currently in preparation.

Content and objective of the code of practice

The aim is to introduce and implement professional risk management measures in order to minimise the size and frequency of losses in the tunnelling industry. The code of practice describes procedures that will assist in identifying risks and assigning them to the parties involved and the project insurers. It also explains how risk evaluations and registers improve the management and monitoring of risks. It is used in all phases of tunnelling projects: development, design, contract procurement, and construction.

Practical applications

The Joint Code of Practice is applied in all tunnelling projects in the UK nowadays. Forerunners of the international version have been implemented in projects in Hong Kong (Kowloon Canton Railway), Singapore (Circle Line), and Turkey (Marmaray Tunnel). In the case of large projects that are placed on the international reinsurance markets on an individual risk basis, application of the code has become a standard condition. The same goes for projects in which the construction of a tunnel is only part of the overall construction work, as in the case of hydropower stations.

Since its introduction, the respective projects have not been subject to any large losses. On their regular visits to construction sites, insurers make sure that the specified risk management measures are being implemented professionally by all those involved. The standards prescribed in the code of practice are largely met nowadays, but it is too early to maintain that the tunnelling risk situation has in general become better and that this is due to the code of practice.

Prospects

The insurance industry expects there to be an appreciable and lasting improvement in the standard of risk management for tunnelling projects, thus reducing the occurrence probability and the effects of loss events. A further aim of the code of practice is to contribute towards keeping such projects insurable.

The success of the code will also depend on the extent to which it is used in the different markets. It is up to Munich Re, as a reinsurer, to convey to its cedants the significance and necessity of the code and join with them in ensuring that it is applied.

Munich Re is represented in the International Tunnel Insurance Group by experienced engineers and is an international market and opinion leader in the insurance of tunnelling projects. Through selective marketing efforts we will continue to raise awareness and acceptance of the code of practice in markets throughout the world so that it becomes an integral part of CAR policies for tunnelling projects.

Further information

The Code of Practice for Risk Management of Tunnel Works may be downloaded at our website www.munichre.com. There you can also order our brochure *Underground transportation systems – Chances and risks from the insurer's point of view* or download it as a PDF file.

Table 1 Tunnelling projects – Major losses 1994–2007

Date of loss	Project	Cause	Loss (US$ m)
1994	Great Belt Tunnel, Fünen-Seeland, Denmark	Fire	33
1994	Heathrow Express Link, London, UK	Collapse	141
1994	Underground, Munich-Trudering, Germany	Collapse	4
1994	Underground, Taipei, Taiwan	Collapse	12
1995	Underground, Los Angeles, USA	Collapse	9
1995	Underground, Taipei, Taiwan	Collapse	29
1999	Sewage tunnel, Hull, UK	Collapse	55
1999	TAV, Bologna-Florence, Italy	Collapse	9
1999	Bolu Tunnel, Gümüsova–Gerede, Turkey	Earthquake	115
2000	Underground, Taegu, South Korea	Collapse	24
2000	TAV, Bologna–Florence, Italy	Collapse	12
2001	Underground, Tseung Kwan O Line, Hong Kong	Typhoon	–
2002	High-speed railway, Taiwan	Collapse	30
2002	Socatop Tunnel, Paris, France	Fire	8
2003	Underground, Pearl Line, Shanghai, PR China	Collapse	80
2004	Underground, Circle Line, Singapore	Collapse	–
2005	Underground, Orange Line, Kaohsiung, Taiwan	Collapse	–
2005	Underground, Barcelona, Spain	Collapse	–
2005	Underground, Lausanne, Switzerland	Collapse	–
2005	Motorway tunnel, Lane Cove, Sydney, Australia	Collapse	–
2007	Underground, São Paulo, Brazil	Collapse	–
Total			> 600

Source: Knowledge Management Topic Network Construction

Crude oil and natural gas

Blowout – An extremely dangerous and complex hazard

The flame shot 60 m into the air when gas escaped from a production well at a natural gas reservoir and ignited: a blowout.

Author
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Blowout: The huge cloud of flaming gas could be seen from miles away.

The underground porous reservoir (cf. Fig. 1 on page 11) in a limestone formation in Poland had a capacity of some 600 million m³. Eight wells had been planned with the intention of extending the storage capacity to 3.5 billion m³ – which would make it one of the largest natural gas reservoirs in Europe.

Two days before the loss event, work was in progress on the fourth well – a deep horizontal well with a projected final depth of 1,500 m. Suddenly, workers noticed a distinct loss of drilling fluid (bentonite mud). As usual in well-driving operations, drilling fluid was being pumped through the bore string to equalise the pressure when drilling into a deposit. This means that some of the fluid must have flowed into adjacent rock. As the fluid losses were continually increasing, an attempt was made to remedy the situation immediately but without success.

The resultant lack of drilling liquid led to the gas escaping from the well bore and igniting. The flame shot 60 m into the air and could be seen from miles away.

Blowout

An uncontrolled escape of oil or gas from an exploration or production well is extremely dangerous. There are only a few specialists throughout the world who can stop blowouts – regardless of whether the well is burning or not. In the initial response, water must be used to cool the surroundings and rescue services. Then the blowout preventer (an array of special valves on the well bore) must be closed or replaced. This is a perilous, technically elaborate, but also lucrative business – one of the most advanced disciplines of fire-fighting.

Difficult fire-fighting operation

After about 30 minutes, the rig collapsed and had to be removed to permit further fire-fighting efforts. It was extremely difficult for the fire-fighters to attach steel cables to the rig fragments, because in order to do so they had to get very close to the flames. Heat-resistant clothing was needed. About 5 tonnes of scrap steel – roughly a third of the original rig structure – had to be removed using special vehicles.

About 200 fire-fighters were involved in the operation, as well as several drilling and mining specialists. A second rig (around 45 m away) and an extraction facility (some 15 m away) were also in danger and had to be cooled continuously along with other units in the vicinity. This required 22 fire-fighters and 16 water tenders. The water soon began to run short but was supplemented with supplies from a natural well about 2 km away. For safety reasons, the police and fire services cordoned off the area and blocked all the access roads.

Stopping the escape of gas

At this point in time, the emergency plan went into action. The operators, the responsible mining authority, and highly specialised mining experts agreed on the measures to be taken to prevent the gas from escaping. Two completely separate approaches were developed: the one involved closing the blowout preventer by injecting water, the other drilling a relief well.

First approach

As the blowout preventer was blocked, it was not possible to inject water at first. It had to be cooled off before it could be removed using a crane. But hydrostatic pressure alone turned out to be insufficient to close the blowout preventer. Time was pressing because leaks seldom remain stable and are capable of eroding. One method of sealing leaks is to use rubber, rubber balls, or even golf balls as sealing elements in the gas stream. In this case, a mixture of water and rubber balls succeeded in stopping the escape of gas. A new blowout preventer was mounted. The emergency operation was successfully concluded within the space of two weeks.

Second approach

The second approach called for a relief well (emergency bore) to be driven about 300 m away. The plan was to pump sealing fluid into the well bore at a depth of some 1,500 m and thus curb the escape of gas. A period of two weeks was scheduled for the drilling. At a depth of about 300 m, however, the work was stopped because the strategy adopted first had already proven successful.

The situation is extremely dangerous. Extinguishing the conflagration and cooling the well are a tough challenge for the fire-fighting teams.

The rig collapses, gas continues to pour out, the heat is enormous. Some five tonnes of steel scrap has to be removed in order to gain access to the blowout preventer.

Cause of loss and insurance coverage

The uncontrolled gas escape may have been caused by a combination of factors: large gas losses and inadequate reserves of drilling fluid and water. In addition, the safety regulations were not properly observed when attempts were made to remedy the losses. When a “critical gas loss” situation had been reached, for example, the well bore was not closed with the preventer and the drill string was not withdrawn. This resulted in large volumes of gas escaping under high pressure and igniting – presumably on an electrical unit. In the final analysis, the explosion and fire were due to faulty performance since the work instructions had not been followed during drilling operations.

The policy covered the damage to buildings and drilling installations and the loss of the stored natural gas as current assets. Business interruption was not insured. Cover existed for all instances of loss and damage, including those resulting from gross negligence on the part of the policyholder’s employees or those of a party specifically named in the policy, which meant that the breach of safety regulations was also covered.

Claims amount and settlement

The initial loss estimate was in the upper seven-figure zloty range but increased very soon to roughly 30 million zlotys. On account of the difficult loss situation, it was necessary to adjust the estimated of repair and replacement costs for the property losses – particularly those of the concurrent rescue operations – and the costs of the loss of gas. Fortunately, no-one was injured.

Clean-up costs in particular often raise the loss amount, since there are only a few specialist firms throughout the world that can do such work and this calls for special equipment. As a rule, it is also a job that can only be given to firms with a mining licence.

Calculating the cost of the gas loss was especially problematical. The first theoretical estimate of ten million zlotys was subject to considerable uncertainty because it had an error variance of 25–50%. In order to be in a position to estimate and weigh up the loss in more detail, measurements had to be performed in addition to complex thermodynamic calculations. With the aid of a mass balance, it was possible to obtain a realistic figure for the loss amount. It was lower than the theoretical figure – but it was also more reliable. The loss amount was consequently put at about eight million zlotys.

There were also claims under third-party liability, e.g. for damaged buildings and roads and for crop losses in the cordoned-off area. These claims also came to several million zlotys. The loss was finally adjusted at approx. 24 million zlotys (approx. €5.5m)

Prevention and control strategies

In the event of a blowout, action must be taken quickly and effectively. Specially designed blowout contingency plans (BCPs) have been introduced internationally which include general rules for emergencies, control strategies, and work instructions. Successful implementation of such plans makes an important contribution towards loss minimisation.

Complex blowout control projects can be realised very effectively – most especially when the drill crew, the blowout control advisor, and the suppliers cooperate in devising and implementing the contingency plan. In the United States, for example, well control incident management systems and blowout control alliances provide valuable services. The National Interagency Incident Management System (NIMS) and the Incident Command System (ICS) were developed in response to dramatic losses in the 1970s.

Conclusion

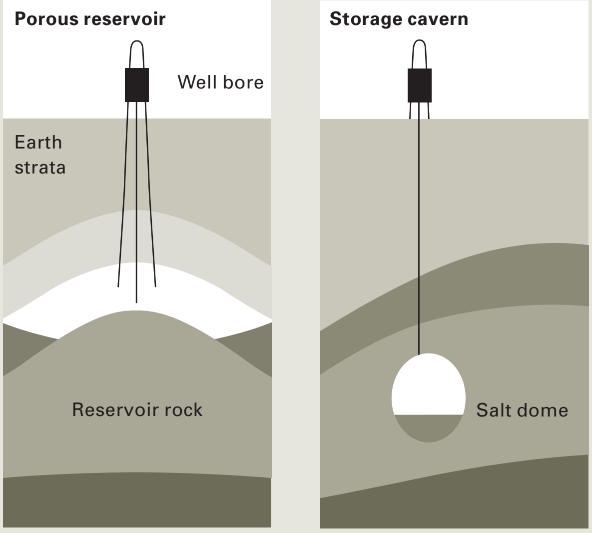
Following the loss event, specific instructions were formulated on the procedures to be adopted following gas losses. Furthermore, the correct response to blowouts is a subject that should not only be addressed in depth when training drill crews; it should also form an important part of their final examinations.

Emergency teams must consider all the possibilities quickly and on an ongoing basis and consider the factors that could lead to a chosen strategy failing: e.g. safety risks, contamination, logistical hurdles, available resources, public interests, and degree of escalation. Multilayer decisions are necessary, particularly when two strategies are pursued in tandem in the process of rectifying the damage, as in the case described above.

Underground gas storage

Natural gas is mainly stored in porous (i.e. aquifer) reservoirs or cavern reservoirs, which are filled during the warmer months when the demand for gas is low. When the weather turns colder, they are emptied to satisfy the higher demand. Porous reservoirs usually cover the seasonal base load, often in combination with cavern reservoirs, which are particularly suitable for covering peak demand at specific times of the day. On account of the natural flow paths in the reservoir rock, porous reservoirs are slower in their response to changes in production rates than cavern reservoirs, which are more comparable to an underground pressure vessel. According to the International Gas Union, there is an installed working gas volume of around 333 billion m^3 available worldwide in more than 600 underground gas reservoirs. Although about 70% of these reservoirs are in the United States and 25% in Europe, Europe's reservoirs account for about 60% of the installed working gas volume and those in the United States only about 35%.

Fig. 1 Schematic representation: Underground storage



Porous (i.e. aquifer) reservoirs consist of porous reservoir rock and are usually depleted gas deposits or strata that used to carry water. Storage caverns are old salt domes.

Control of well insurance

Author
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The exploration and production of hydrocarbons produces an array of hazardous risks to oil and gas companies. In addition to the obvious risk of the physical loss or damage involving production facilities, the industry has to consider many other additional exposures. These include in particular the risk of blowouts. Such events can often be dramatic in terms of the financial loss, environmental impact, and reputational damage. Transparent and reliable risk transfer is provided by control of well insurance.

As described in the account beginning on page 8, the uncontrolled escape of gas or oil from a well bore occurs when the formation pressure exceeds the hydrostatic pressure provided by the column of drilling fluid, commonly termed "drilling mud", in the well bore. If the well cannot be brought under control again, either by means of the surface equipment or by increasing the weight of the drilling mud, a blowout is inevitable. Such a situation is not only immensely hazardous, it can also be extremely expensive.

Blowouts can develop in very different ways. In some cases the well bore collapses below the surface and the flow ceases. Other cases may involve a situation in which the well continues to flow uncontrolled for many months, causing significant pollution and financial loss.

Insurance

Control of well insurance was developed over 50 years ago in order to provide a clear and dependable risk transfer solution, but the scope of cover has changed considerably in the course of time. Indemnification initially extended only to the costs of responding to a blowout (known as control costs), consisting of costs associated with capping the well, fighting the fire, and possibly drilling a relief well.

It soon became apparent that the financial loss to the oil and gas company was much broader than this. There is the additional cost of re-drilling or restoring a well following a blowout and the possibility of liability for any pollution the blowout may cause. This matrix of potential losses that may be incurred following a blowout is reflected in the additional covers that are available from the market today.

EED (8/86) – Basis for policy wordings

The complexity and exposure of the risk led to the development of the Energy Exploration and Development wording in 1986 by the London market. Commonly referred to as EED (8/86), this wording is still the basis for the majority of covers on offer in the market today. EED (8/86) successfully translates the intent of coverage into contractual clarity. For instance, the wording considers the issue of excluding coverage for what are called "kicks". These are uncontrolled flows of oil or gas into the well bore which are, however, contained by way of appropriate remedial action. Kicks may cause additional expense for the oil and gas company but they are deemed to be non-fortuitous events by the insurance industry and therefore not insurable.

The following brief analysis of the wording provides a good overview of the covers currently on offer. There are three main sections of coverage: control costs, costs for re-drilling, and costs for seepage and pollution liability.

The key element of the wording is that cover is triggered by a "well out of control":

"For the purposes of this insurance, a well(s) shall be deemed to be out of control only when there is an unintended flow from the well(s) of drilling fluid, oil, gas or water above the surface of the ground or water bottom,

– which flow cannot promptly be
  · stopped by use of the equipment on site and/or the blow-out preventer, storm chokes or other equipment required by the Due Diligence and Warranties clauses herein; or
  · stopped by increasing the weight by volume of drilling fluid or by the use of other conditioning materials in the well(s), or
  · safely diverted into production, or
– which flow is declared to be out of control by the appropriate regulatory authority.

Nevertheless, and for the purposes of this insurance, a well shall not be deemed out of control solely because of the existence or occurrence of a flow of oil, gas or water into the well bore which can, within a reasonable period of time, be circulated out or bled off through the surface controls."

This definition is the critical element of the wording. It defines the point at which coverage is activated. The coverage then ceases as soon as the well has been brought under control. This, too, is subject to a precise definition in the wording.

In the event that the well is deemed "out of control", any applicable well re-drill or restoration costs are also recoverable. Such coverage would not include betterment of the well but is limited to costs incurred as follows:

"Underwriters shall be liable for costs and/or expenses incurred

- with respect to drilling wells, to drill below the depth reached when the well became out of control as defined in Clause 2 of Section A of this policy and

- with respect to producing or shut-in wells, to drill below the geologic zone or zones from which said well(s) was (were) producing or capable or producing."

Pollution cover can also be included, indemnifying the oil and gas company for clean-up and remedial costs for which it is legally liable.

In addition to these three core lines of coverage, there are some important optional coverages. Firstly, coverage is available for the risk of an underground blowout; this provides for the indemnification of costs incurred in controlling the unintended flow of fluids from one subsurface zone to another via the well bore. Although this coverage extension may seem to have limited impact, it should be noted that this cover is a major risk potential for the insurer. Another optional coverage is for physical damage to equipment under the care, custody, and control of the oil and gas company. Coverage is only provided for loss or damage caused by a "well out of control".

Risk assessment

Having determined the scope of coverage and the number and nature of the risks being presented, the underwriter has to set the appropriate premium levels. In general terms, the premium charged depends on the depth of each well – the deeper the well, the higher the premium. This basic rate (€ per metre of well depth) is then subject to a modifier, which is dependent on such factors as the geographical location of the well, the status of the well (exploration, field development, or production), the limit requested, the deductible, and the cost of the well.

Furthermore, since human error is often a key contributor to loss, specific attention will be paid to the experience of the oil and gas company and the drilling contractor and to the quality of the equipment employed. There is often a disproportionate increase in the frequency and severity of loss if the drilling plan is inadequate or the drilling crews are inexperienced and have to use poor equipment.

In the light of such factors, experience and expertise are necessary to assess the risk properly. If the geological conditions in a certain geographical area are known and the industry has years of experience in drilling there, the likelihood of blowout in that area may be low. In areas that have been less extensively explored, the risks are much higher and require considerable premium loadings. For example, a 7,000-m exploration well being drilled offshore in 1,500 m of water in the Gulf of Mexico is a much greater risk than a 1,000 m development well onshore in Canada.

In a volatile and difficult class of business like control of well insurance, it is very important to mitigate the risk as much as possible. Procedures such as demanding an independent review of drilling plans, or a survey of the drilling rig and its critical components can both improve the risk for underwriters. Furthermore, requiring the oil and gas company to have a dependable contingency plan in the event of a blowout can result in considerable post-event loss mitigation.

Overview of loss developments

In the years 1990–2005, the average loss per annum for losses exceeding $1,000,000 was $320,000,000. This does not include the impact of windstorm losses in the Gulf of Mexico, where, in 2005, Hurricanes Rita and Katrina gave rise to considerable loss payments for re-drills or well restoration (approx. US$ 1.7bn)[1] in connection with property damage to the rigs.

Control of well insurance is a difficult and demanding insurance product which has to respond to continuous changes in technology and environment. Its particular features require that the job of assessing risks and designing insurance solutions is exclusively reserved for specialists. Underwriters must have solid technical knowledge of and experience with this kind of cover and sound commercial judgement. Only then can the oil and gas industry be offered attractive insurance protection which facilitates a risk transfer that is not only reasonable and sound but also fair for both sides.

[1] Willis Energy Loss Database.

Environmental liability risk

Remediation of a former gasworks site

Former gasworks sites must generally be regarded as suspected contaminated sites. Experience shows that the pollution of the ground and groundwater is particularly great there – and that remediation usually takes a long time.

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When the municipal gasworks was shut down in 1968, the operating facilities were dismantled. In the subsequent years and decades, the pollution of the soil by tar oil and benzene was forgotten.

Shortly before a municipal gasworks was shut down in 1968, 1,500 litres of benzene seeped out due to a broken pipe. These kinds of accidents, plus the escape of typical by-products of the gasworks operations (tar oils, hydrocarbons, etc.), had been nothing unusual over the decades. Hardly any notice was taken of the fact that these substances were detrimental to the environment. Surplus tar oil was buried in simple earth pits on the site, for example, or "disposed of" in abandoned units, e.g. in the brick-walled bases of shut-down gas-holders (gasometer tanks). In this way, the pollutants were able to get into the ground and the groundwater.

1968 – Operations are stopped

Pollutants had also seeped into the ground regularly on the 3-ha site of the municipal gasworks since it first went into operation in 1865. When the plant was shut down, the coking plant, the gasometers, and other units were dismantled. Only the machine room continued to serve as a workshop. The tar pit and the gasometer tanks were filled with building rubble, a large part of the site was developed with office buildings, and the spaces in between sealed with asphalt. As time went by, the ground pollution was largely forgotten.

In the years that followed, the site was first used by the municipal energy and water supplier, which the city later hived off as an independent operating company. This company is the owner of the property and legal successor to the former gasworks.

1994 – Contaminated site investigation

The authority responsible arranged for the contaminated site investigation in 1994. To put it in a nutshell, the investigation dragged on for years. The soil and groundwater examinations were carried out in stages and concentrated on the former operational site without, however, considering the groundwater runoff.

Composition of the subsoil

The ground on the site consists of white sandstone layers up to 6 m thick alternating with layers of red mudstone about 3 m thick. The individual sandstone layers are only partly filled with groundwater and are sealed by the mudstone below each sandstone layer, thus forming a number of separate groundwater storeys.

Initial results of the investigations

The first results confirmed what had already been expected: the tar oils' greatest impact was on the gasometer tanks, the tar pit, the soil underneath, and the ground below the former machine room. There was extreme benzene pollution in the region of the fractured benzene pipe. The ground and groundwater outside these main areas were also found to be polluted and in need of remediation.

However, groundwater velocity was so low that even after an operating period of 100 years, the pollutants had only formed a 200-m-long plume in the groundwater. This was only discovered during a later investigation when soil remediation was already under way.

1999 – Remediation planning

Since the investigations had already been dragging on for several years, the authorities finally issued a remediation order in 1999, requiring that a remediation plan be submitted without delay. This had to be drawn up at such short notice that there was no time to weigh up the various alternatives properly.

The plan provided for remediation of the entire site by means of soil replacement, with the exception of the areas that were already built on. The polluted top sandstone layer was to be excavated, removed, and replaced by clean soil. The layer of mudstone beneath, which was assumed not to have been polluted, was to serve as the bottom level of the excavation. In addition, the machine room had to be partly pulled down because the ground was heavily contaminated by tar oils. The ground beneath the rest of the building would be structurally encased. The site's groundwater runoff would be monitored and regularly cleaned for as long as possible.

The authorities approved the remediation plan and pronounced it to be binding in accordance with the German Federal Soil Protection Act now in force.

2000 – Soil remediation

Excavation involved considerable time and expense because when the units were dismantled in the 1960s, their foundations had not been demolished. The tar pit was removed without any difficulty but the gasometer tanks had to be dismantled once they had been emptied. The contaminated ground substance was removed and the soil below it was replaced. The remediation of the benzene damage had to be carried out under the protection of a special enclosure because of the danger of toxic degassing.

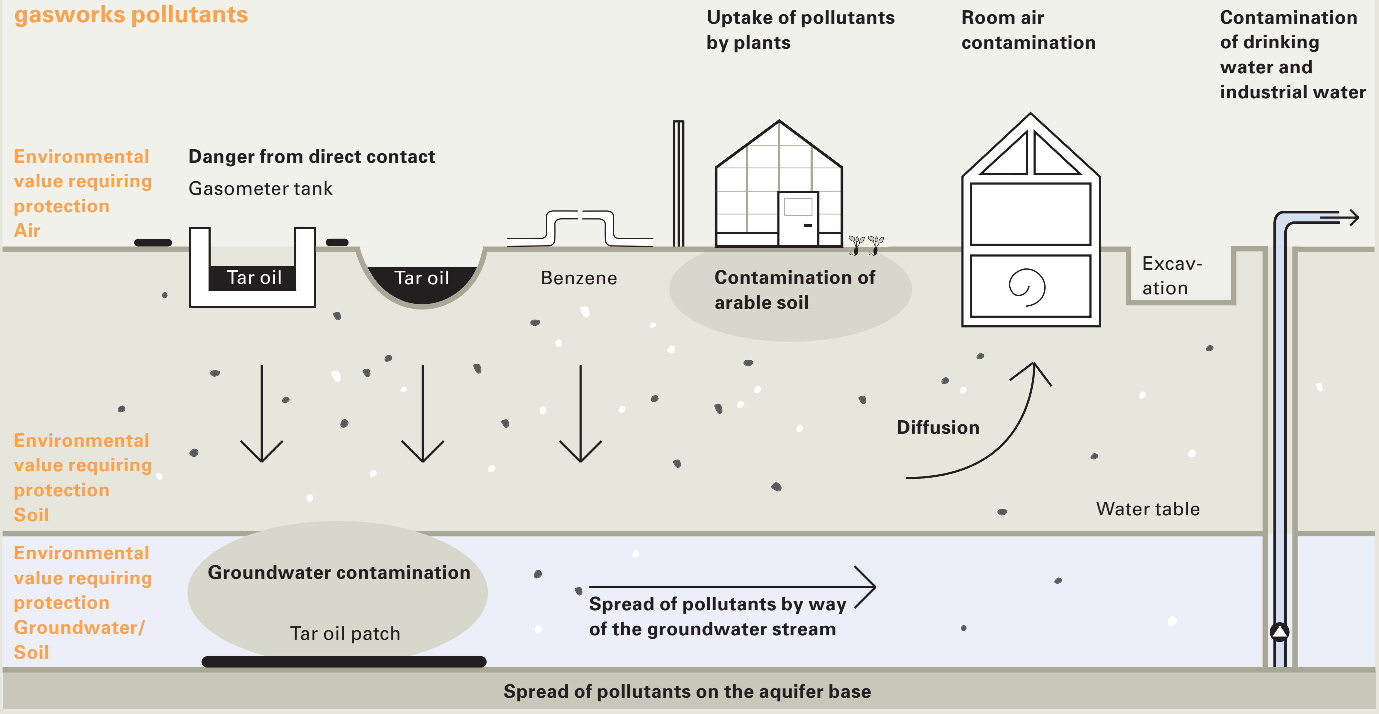
Town gas, urban energy

In Germany, town gas came into use in the second half of the 19th century, at first for street lighting and later to supply households with energy. Almost all towns and cities ran their own gasworks. The majority of plants were shut down in the 1960s, however, when crude oil and natural gas stocks were developed and used on a large industrial scale.

Town gas, a mixture of methane, hydrogen, and carbon monoxide, was obtained from hard coal by degassing in coking plants. Besides gas, there were also liquid by-products, primarily benzene and non-volatile tar oils, plus sulphuric acid and ammonia. These substances were reprocessed by the chemical industry. What remained of the hard coal after carbonisation was porous coke, which was subsequently used in the iron and steel industry.

Today, these by-products put a heavy strain on the environment. Benzene and tar oils are toxic and carcinogenic. The vapours from these substances can penetrate underground parts of buildings and, in the worst case, form explosive mixtures with air. If the substances enter the ground or the groundwater, they are poorly biodegradable. If ground pollution is not identified, land development will subsequently involve large amounts of time, effort, and expense for protection and disposal measures. Former gasworks sites are therefore regarded as suspected contaminated sites which must be examined thoroughly before they can be used again.

Fig. 1 Potential hazard paths of gasworks pollutants



Tar oil escapes

During the excavation of the remaining area, it was found that the tar oils had not spread extensively in the pore cavities of the sandstone but had merely advanced along bedding planes and fissures and were bound there. It was only when the ground was excavated that the tar oil began to seep out and flow freely.

In other words, the pollutants had been concentrated in a small volume of soil and were bound there as long as the subsoil remained undisturbed. There was only a possibility of pollutants being mobilised in places where contaminated sandstone came into contact with groundwater. The benefits of a full-scale remediation were thus questionable in both ecological and financial terms. An alternative would have been to stabilise the large-scale soil pollution using appropriate structures. Since the remediation plan specified that the site should be decontaminated, however, the ground was dug out completely – regardless of the degree of contamination.

Mudstone layer is polluted

Contrary to the assumption that the mudstone would form the bottom level of the ground excavation, it was found that under the machine room tar oil had penetrated right through the sandstone and had infiltrated the mudstone layer in some places through fossil, sand-filled cracks in the surface. Owing to the specifications of the remediation plan, however, the ground was excavated completely, thus creating a connection to the deeper groundwater storey.

The extensive opening in the mudstone had to be sealed again afterwards by a concrete plate, requiring an engineering effort that pushed up the remediation costs even further.

2001 – Costs and insurance

The excavation work was not completed until the autumn of 2001. Some 40,000 tonnes of soil had been excavated and replaced. Beneath the machine room, 2,700 cubic metres of heavily contaminated subsoil were encased by a bored pile wall. The open space was completely sealed to prevent any leaching of residual pollutants due to seeping precipitation. Since then, the groundwater runoff has been pumped off regularly, cleaned, and then discharged into the sewage system – an operation that will probably have to be repeated for a very long time to come.

The remediation plan implemented in 2000 included a large-scale excavation of the soil down to a depth of 5 m – not the most favourable solution in either economic or ecological terms.

Soil remediation, dismantling, encasing, and surface capping cost more than €5m. The annual costs of constant groundwater remediation come to about €60,000.

Not having been informed immediately about the preliminary investigations and the remediation plan, the insurer was in no position to exert any influence. Although the company had taken out environmental liability insurance, the policy did not cover all the losses. After a series of difficult negotiations – due to recurrent problems in clearly identifying the cause and inception of impairment – the insurer paid €250,000 towards the remediation costs for the benzene damage: these costs were indemnifiable because the consequential damage occurred within the insured period. The insurer did not pay for the full-scale soil remediation, however, because these losses occurred before the commencement of the policy period. What is more, they were operational losses and not accidents.

Conclusion

The remediation of suspected contaminated sites is complex and often takes time, especially because the interests of the parties involved are often different. In the case under review, the relationship between the company and the responsible authorities was strained. The contaminated site investigation had dragged on for years before the authorities finally issued a remediation order. In some cases, assumptions were the only basis for assessing the hazard because the preliminary investigations had concentrated on specific aspects and were restricted to the site itself. Little use was made of the advantageous hydrogeological conditions in the process of remediation. In financial and ecological terms, there would have been more favourable solutions than complete remediation, although this only emerged in the course of the work. Since the ground had bound the pollutants, it would have been possible to restrict remediation to exchanging the soil in the highly contaminated areas. An engineering solution – e.g. sealing and pumping off the groundwater – might have been a more economical way of dealing with the residual contamination.

Environmental risks are not always recognisable at first sight. It is well worth partnering and supplementing a company's environmental management. Where suspected contamination is concerned, professional support is already advisable in the phases of site investigation and remediation planning. Besides this, a comprehensive risk analysis is indispensable before issuing a policy. The insurer in this case was only spared a considerably higher share of the costs because the losses were operational and the legal period of limitation had expired.

By the time the tar oil (black veins) was discovered to be bound in the sandstone, it was much too late. It was only when the ground was excavated that the tar oil began to flow.

The profile section shows the tar oil contamination in the white sandstone. No-one had expected that the surface of the red mudstone (to the right of the trowel) would also be polluted.

Environmental impairment – Liability and cover

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Contamination through environmental damage can happen suddenly or as part of a gradual process. Contamination restricted to the operating site of an industrial company is considered a first-party loss; if adjacent property is polluted, it is a third-party loss. Historical pollution is when soil or groundwater was contaminated a long time ago, but the damage was not discovered until much later.

Liability

Liability for environmental damage varies significantly internationally. In terms of civil law, liability for compensation usually lies with the party at fault for the damage suffered by the injured party. By contrast, the law frequently stipulates strict liability for industrial plants that are potentially dangerous but which society cannot do without. In such cases, it does not matter whether the party that caused the damage acted negligently or with intent.

Besides the civil liability claims, there are also public-law claims on the part of authorities. These are designed to avert risks to the public or to public protective goods such as drinking water. Although they are primarily directed at the perpetrator of the damage, they can also include other people, such as the owner of the property from where the hazard emanates.

Cover

Environmental damage is covered by a variety of insurance products. Basically, there are the following types of policy:

- Standard policies in liability and property insurance, which, however, cover only a part of the environmental risk
- Special environmental policies, which offer policyholders a broader scope of cover

In many markets, sudden and unexpected environmental damage is covered under public liability policies, although first-party losses are usually excluded. On the other hand, environmental damage caused by products is covered under public liability. Professional indemnity insurance also usually covers environmental damage. Motor policies cover environmental damage caused by the operation of a vehicle. Even fire insurance can cover property remediation as a result of a fire, either in full or with a sublimit.

All of these policies only cover damage to persons and property and, in a few cases, also pure financial losses, caused by environmental impact. However, there are special policies which cover damage to the environment itself, i.e. to water, land, flora or fauna. In contrast to the narrow scope of the standard covers, these policies offer substantially more:

- Environmental liability insurances cover the costs of environmental damage to third parties due to sudden and accidental losses. In addition, they also cover most environmental pollution attributable to the gradual and unintended release of substances. In some cases, environmental damage is covered which is due to operational and officially authorised emissions.
- Clean-up policies – usually restricted to incidents – cover the costs of ground and also in part water damage on the policyholder's property.
- A mandatory insurance for the disposal of waste is frequently prescribed by the authorities.
- Special professional indemnity policies insure companies that provide services in the environmental sector.
- Historical pollution insurances cover damage from unknown land or groundwater pollution.
- Historical pollution remediation insurances cover cost overruns which occur in connection with the remediation of historical pollution.

All of the above-mentioned products are fairly common throughout the world. In many countries, environmental damage to third parties caused by a sudden and accidental loss is covered under public liability policies. In other important markets, special policies tend to dominate.

Further information

The subject of environmental liability was discussed in depth in the 2/2006 issue of our client magazine Topics. You can order the magazine or download it as a PDF file from our website www.munichre.com.

Geothermics

Geothermal heat – Power from the depths

Volcanoes, geysers, hot springs – in some places on the earth's surface the immense energy hidden within its depths is particularly evident. Modern technologies make the climate-friendly and regenerative resource of geothermal energy utilisable. The greatest hurdle for investors up to now has been the productivity risk – but Munich Re has an innovative solution for that, too.

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Blue Lagoon, a geothermal power plant in Svartsengi, Iceland. Water at a temperature of about 240°C is drawn from a depth of 2,000 m – a climate-friendly source of energy.

Geothermics is the science of the heat stored in the upper part of the earth's crust and the attendant technology of bringing it to the surface and using it. Geothermal energy can be used directly for heating or for generating electricity. It is practically inexhaustible and counts as one of the renewable energy sources.

Internal heat

On average, the temperature inside the earth increases by 3°C every 100 metres. The temperature gradient[1] may be subject to strong local fluctuations, however. Such deviations are called heat anomalies. Particularly steep temperature gradients mostly occur in regions that are also prone to volcanic activity. In such regions, rocks with a temperature of several hundred degrees are found at shallow depths.

On the German side of the Rhine Rift between Frankfurt and Basle, for example, the temperature measured at a depth of 3,000 m is 130°C, whilst on the French side, in Soultz-sous-Forêts, Alsace, it already reaches 100°C only 1,000 m below the surface. Soultz-sous-Forêts is home to the pilot plant of the European Geothermal Project, which since 1996 has combined the technological research activities that various countries have been carrying out on the hot dry rock (HDR) process.

Economic use

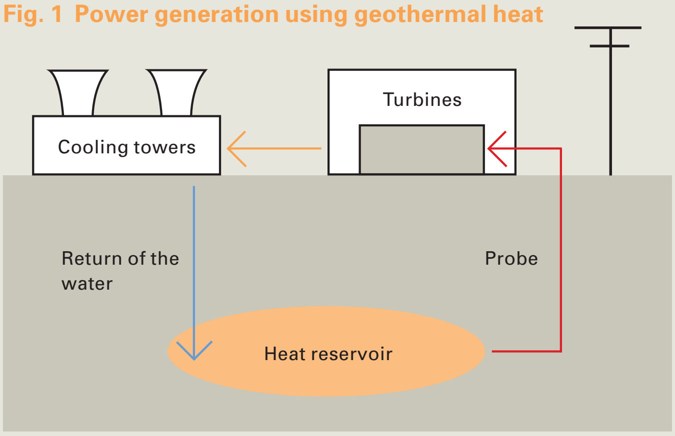
The first geothermal power plant was built in Larderello in Tuscany in 1904: it had an output of 250 kW. Worldwide exploitation of geothermal energy on a large scale began at the end of the 1970s. In 2000, the United States had the largest installed electrical capacity of 2,300 MWe. As far as the use of thermal energy for heating is concerned, China led the world in 2000 with a rate of 10.5 TWh/a – ahead of Japan (7.7 TWh/a), the United States (5.6 TWh/a), and Iceland (5.6 TWh/a), where geothermal heat accounts for approx. 53% of the country's power supply.

Potential uses in Germany

In principle, Germany has three possible ways of obtaining heat energy from the depths of the earth: tapping near-surface geothermal resources, driving deep wells, and applying hot dry rock processes. However, only the second two have any major economic significance.

Near-surface geothermal energy is used to heat or cool individual buildings decentrally. For heating purposes, geothermal energy probes are installed at depths of 30–150 m between which a heat-carrying medium circulates. A heat pump converts the thermal energy into heating energy.

Fig. 1 Power generation using geothermal heat



The energy of natural underground hot water aquifers reaches the power station via a heat exchanger. The cooled water is pumped back into the ground through a second well.

Deep wells can be driven into natural underground hot water systems, so-called hydrothermal systems. The hot water is transported to the surface through a well, and the energy transferred by means of a heat exchanger into a secondary circuit with which a heating system or a power station is operated. The water, which has cooled down in the meantime, is then pumped back into the ground through a second well. Fig. 1 is a schematic representation of such a system.

The hot dry rock process, or petrothermal system, is the third possibility of heat extraction. Cold water is injected under high pressure through a deep well into hot dry rock layers, where it causes cracks and fissures in which it can then circulate and act as a heat carrier. The heated water is then transported through a second well, which is linked up to the crack and fissure system of the first well by injecting cold water, too.

For electricity generation to be economical, temperatures of more than 150°C are generally needed (high-enthalpy deposits) but the new Kalina process also makes it possible to use low-enthalpy deposits with lower temperatures (of 80°C and above). In the Kalina process, an ammonia-water mix is employed in the turbine circuit with a lower or variable boiling-point as the operating media. Unterhaching, Germany, is one of the four power plants worldwide that are making use of this process.

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[1] The spatial change in temperature in a thermodynamic system.

Drilling rig for the first well in Unterhaching.

Drilling bit (23-inch) in the bore of the first well.

Future technology

The German parliament's technology assessment office estimates the total potential of geothermal energy to be 300,000 TWh. But electricity generation by means of geothermal energy is still in its infancy in Germany. At present, electricity is only produced in this way at one power station (Neustadt-Glewe). In 2007, at least three more geothermal power plants (Unterhaching, Landau, and Bruchsal) are planned to go on grid.

In 2004, geothermal energy accounted for only 0.04% of Germany's primary consumption, but the industry expects to achieve an annual growth rate of 14%. It is assumed that by the end of 2007, some 100,000 decentralised units with geothermal probes and heat pumps will be installed in Germany besides the four geothermal power plants. The high investments will pay off because the prices for fossil fuels will continue to rise and because the generation of electricity from renewable sources is promoted by the federal government's Renewable Energy Sources Act.

Productivity risk

The greatest investment risk in geothermal power generation is the productivity risk linked with deep wells because at the time the costly drilling operations begin, there is no certainty that thermal energy can be delivered in sufficient quantities for the plant to run economically. Even if the temperatures can be forecast quite well, the flow rate is difficult to estimate.

In the meantime, however, an insurance solution has also been developed to deal with this risk. An insurance contract was successfully concluded for the first time in connection with the project in Unterhaching. It covered the risk of project failure, i.e. the production of less than 65 litres per second, or partial success, the production of more than 65 but less than 100 litres per second. In addition, the concept also included stimulation measures to improve the flow rate if it turns out to be lower than expected after the completion of the well.

Productivity risk insurance covers the loss that would be incurred if, despite stimulation measures, the well yielded such poor results that continuing the project would not be worthwhile. The maximum possible loss is calculated as the costs of drilling plus the expenses of any stimulation measures that may be required.

Further risk aspects

Besides the productivity of the well, a further risk is the possibility that a plant cannot run for its entire projected service life because the geothermal field cools down faster than the rate used in the initial calculations or because the performance of the well declines in the course of time. These aspects should be taken into account at the planning stage of the project since no insurance solution for them has yet been developed.

The drilling works themselves are a complicated matter, and many technical difficulties may be encountered before the drill head reaches a depth of several thousand metres. Property insurers offer various covers for this stage of the operations: drilling/engineering insurance (for drilling companies/operators) or CAR and EAR insurance at the bore hole and on the construction site of the geothermal energy plant (for operators).

Rumbling after drilling

When the earth shook in Basel on 8 December 2006, it triggered a discussion on the risk that geothermal drilling operations may cause artificial earthquakes. Although it was known that minor seismic shocks can occur, the fact that a magnitude of 3 on the Richter scale was exceeded on three occasions in December 2006 and January 2007 – with almost 20 seismic shocks altogether – surprised even the experts. It had been assumed – partially due to the experience gained in the course of the HDR project in Soultz-sous-Forêts – that magnitude 3 represented a kind of upper limit as far as geothermal earthquakes were concerned. The situation is currently being analysed in even more detail in order to gain a more adequate understanding of the connections between the injection pressure of the water, the tectonic conditions, and the size of the earthquakes.

Further information

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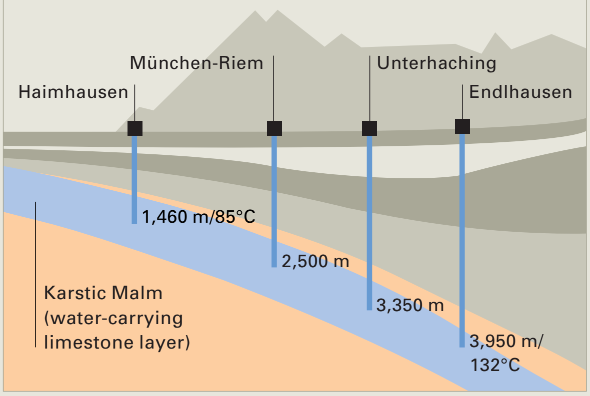
Prestige project in Unterhaching

Drilling work on Germany's deepest geothermal well began to the south of Munich in 2006. The municipality of Unterhaching started drilling down to a depth of more than 3,300 m in order to draw thermal water which would supply energy for a cogeneration plant and a district heating system. The costs for the project as a whole are roughly €50m, including over €4m for the first well (2004). To protect this initial investment, Munich Re's experts developed Europe's first private-sector productivity risk insurance in a unique pilot project. It was a major challenge because there were no comparable plans available and the data needed to calculate the risk were rudimentary. The pilot project was successfully completed despite various technical problems. Water measuring 122°C will be produced at a rate of more than 150 l/sec to drive a 3.4-MW electricity turbine and supply a district heating system. The plant is to go on grid in the autumn of 2007.

Fig. 2 North-South cross-section of the Alpine foreland



Areas with solid sedimentary rock are particularly suitable for hydrothermal geothermal energy projects, as in the case of the Molasse basin south of the Danube in Bavaria.

Source: Rödl & Partner GbR, Unterhaching

On 17 January 1995, a 500-m stretch of the elevated carriageway tipped over on the Hanshin expressway in Kobe, Japan. The remarkable thing was that numerous multi-storey buildings in the immediate vicinity remained undamaged.

Special topic: Earth – When the forces of nature become a danger

They are triggered by activity in the earth: the geo risks of earthquake and volcanism.

Special topic: Earth – When the forces of nature become a danger

Earthquake review 1994–2006

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Schadenspiegel looks back at earthquake events for the third time since 1984 and focuses this time on the last 13 years. On the basis of the greatest catastrophes, we analyse the current risk situation, report on what has been happening in the fields of research and prevention, and explain how the insurance industry is adapting to the natural hazard today.

In the very first two years of the period under review, two of the greatest urban earthquake catastrophes of recent decades occurred in highly developed countries: the United States and Japan. On 17 January 1994, the San Fernando Valley 30 km northeast of Los Angeles was shaken by a magnitude 6.8 earthquake with its epicentre in Northridge. 61 people died. The overall loss came to US$ 44bn, of which US$ 15.3bn was insured. Nothing approaching this amount had ever been paid for earthquake losses up to then.

Exactly a year later, on 17 January 1995, a 6.8 earthquake struck again, this time in Kobe, Japan. Over 6,000 people were killed. The overall loss was more than twice as high as in Northridge. Since the proportion of insured values was much lower, however, insurers had to foot a bill of “only” US$ 3bn.

The faults did not break through to the earth’s surface on either occasion. The acceleration forces are particularly high in such earthquakes. In both events a phenomenon known as fault fling was also observed. This refers to a long-period pulse of energy which constitutes a particular danger to higher buildings in the immediate vicinity of a fault.

The period under review also includes the tsunami which followed the quake in the Indian Ocean off the coast of North Sumatra on 26 December 2004. It triggered the worst human disaster caused by a natural hazard event since the earthquake of Tangshan, China, in 1976. At least 210,000 people were killed. The overall financial loss came to US$ 10bn, of which approx. US$ 1bn was insured.

An analysis of the last 13 years reveals particularly clearly how the loss pattern in emerging countries and third-world countries differs from that in highly developed regions. In the areas with high concentrations of values and high market penetration the number of fatalities is relatively low, whereas in the others there is an above-average death toll whilst insured losses are comparatively low.

Blind thrust faults – An invisible danger

The earthquake in Northridge turned the spotlight onto blind thrust faults, i.e. invisible faults. Running under the earth’s surface, they are not easy to identify or examine, which makes it particularly difficult to register which earthquakes are linked with them. The strongest ever earthquake of this type occurred completely unexpectedly in the Indian state of Gujarat on 26 January 2001. It had a magnitude of 7.7.

The phenomena that cause the great destructive force of these earthquakes are not unknown, however:

- The hanging-wall effect refers to the fact that the ground motion is higher in the crustal block, which is moved along the fault in a relatively upward direction (hanging block), than in the block lying below it. This causes the formation of strongly asymmetrical intensity fields, as was clearly seen in Northridge.

- Since the fault does not break through to the earth’s surface in this kind of earthquake, there are very high accelerations. Many measurements that have been performed in the meantime show acceleration rates of up to 2 g. Such high values were long considered to be the exception.

Kobe, Japan, 17 January 2005. The damage to the town hall was typical. The middle storey of the old town hall collapsed. The new high-rise building, erected in accordance with the current building regulations, stood firm.

Loss minimisation through earthquake-resistant construction

In less developed regions of the earth, the numbers of victims are particularly high because the buildings are very vulnerable. But immense losses still occur in industrial countries, too – and it is not only the older buildings that are affected. In the case of the Northridge earthquake, for example, the engineering world was astonished to find that even the steel-frame structures, which had been regarded as quite stable, had suffered considerable damage. This was only discovered months after the event and had a worldwide impact on the earthquake-resistant design of such buildings.

The amendment of building regulations has its effect – as long as the new regulations are observed. In Kobe, for example, the buildings that had been built after a revision of the building code in 1981 largely survived the 1995 earthquake. On the other hand, the buildings built prior to these amendments suffered enormous damage due to their inadequate ductility. One particularly characteristic feature of the loss pattern was that the middle storeys of buildings with 10–15 storeys failed as a result of resonance with resonance periods of the second order (also called secondary resonance modes) or vertical changes in the steel reinforcement.

Japan is a country with very high standards of seismic safety. The extreme size of the loss from a potential earthquake of intermediate magnitude came as a surprise, which makes this event even more important as a basis for assessing the results of an earthquake in Greater Tokyo, where the concentration of values is many times higher than in Kobe.

In August 1999, the earthquake in Izmit, Turkey, showed how drastic the implications can be if building regulations are not adhered to. The illegally assembled buildings of the underprivileged sections of society were less affected than the multi-storey blocks of flats of the middle classes, which had been erected at high speed and with correspondingly poor quality on the strength of sometimes dubious approval processes.

A further negative example is the earthquake that rocked Athens the same year. In spite of a magnitude of only 5.9, the earthquake caused an overall loss of US$ 4.2bn. The reasons: inappropriate construction methods and failure to comply with the building regulations. But there are also reports of innovative solutions from Athens. Current building projects include the Onassis House of Letters and Fine Arts and the new Acropolis Museum. Both of these structures are being built on gliding-surface bearings and are thus decoupled from the underground by means of passive base isolation.

Where high-rise buildings are concerned, solid steel structures are still preferred as a means of avoiding strong vibrations. An example of this is Taipei 101, a high-rise building in Taiwan, which is, however, “stabilised” by a 660-t pendulum.

In the meantime, in cases involving more complex buildings for which standardised building regulations are not suitable, the approach increasingly being chosen is “performance-based design”. This is not based strictly on standardised codes but necessitates tailor-made solutions. Fundamentally, it is up to the architects and engineers to ensure that the building remains intact after an earthquake of intermediate strength and that it does not collapse after a strong earthquake. However, this presupposes that the architects cooperate closely with the engineers.

There are many options available for reducing the vulnerability of buildings – but they all call for a sense of commitment. In addition, laws must be enacted, adapted, and enforced. Of course, amendments and new building codes take time to be effective. Therefore, older buildings must also be examined in order to ascertain the extent to which they can withstand earthquake events or how their level of safety can be raised by subsequent improvements.

In less developed countries, the necessary know-how is often lacking as well as the financial possibilities. To achieve more safety in future, a more intensive exchange and transfer of knowledge would be desirable. Munich Re has therefore become a partner to GeoHazards International (GHI), an organisation which contributes towards the reduction of losses from natural catastrophes primarily in developing countries by means of education, disaster preparedness, and loss prevention.

Izmit, Turkey, 17 August 1999. Multi-storey blocks of flats which had been built without adherence to the building regulations suffered the worst damage.

Athens, Greece, 7 September 1999. Here too, much of the damage could have been avoided by paying attention to good construction work and observing the regulations.

Disaster management

The great 1906 earthquake in San Francisco revealed the importance of disaster management. At the conference held in San Francisco in 2006 to mark the 100th anniversary of the earthquake, it emerged that although plans are in place to cope with a catastrophe in the time immediately after the event, it is still not perfectly clear how to proceed when it comes to the reconstruction of the damaged areas and infrastructure. As the extent of an earthquake and its effects are only foreseeable to a certain degree, a mixture of systematic and pragmatic action would be the optimal solution. This applies not only to San Francisco but to all earthquake-prone regions.

What happens when preparations are inadequate was shown by the devastating effects of the Izmit earthquake, which claimed the lives of about 15,000 people. At least, conclusions were drawn from this, with an intense discussion as to whether Istanbul is threatened by another earthquake to be expected even further west. Will the city be better prepared for the next earthquake? The question can be answered, to a certain extent, in the affirmative. For example, the new gas network was designed especially to cope with earthquakes. In addition, an early warning system is being planned which will ensure that particularly critical plants are switched off.

Action was taken soon in response to the tsunami in 2004. The Tsunami Early Warning System (TEWS) is currently being installed in the geologically most critical zone of the Indian Ocean, the Sunda Arc. By addressing the technological aspect, the project serves to raise awareness of the hazard among the population potentially concerned and the decision-makers and creates the infrastructure needed to ensure delivery of the warning and the appropriate response.

Predictability

Although distinctive progress is being made in terms of modern measuring technologies and the installation of early warning systems, there is still an element of surprise. The earthquake in Athens came completely unexpectedly, for example. After all, no comparable event had been documented at any time in the city's long history, which goes back more than two-and-a-half millennia. The experts were also surprised by the 1999 earthquake in Taiwan, as the occurrence probability of an earthquake of this strength in the epicentral region had been assessed to be only once in 10,000 to 100,000 years.

The assertion that immediately after an earthquake occurs there is a steep drop in the probability of another earthquake occurring has already been disproved on various occasions. In fact, the probability increases in the immediate vicinity of the rupture zone. In the year 2001, for example, San Salvador was shaken by two earthquakes in the space of a month. The epicentre of the first, with a magnitude of 7.7, was off the Pacific coast, whereas the second, with a magnitude of 6.5, was on the mainland. This is because the forces released in the first earthquake accumulated again in another area, resulting in a further earthquake shortly afterwards. The same phenomenon applies to the two earthquakes that hit Izmit and Düzce in close succession in 1999.

In Gujarat, too, the earthquake came far earlier than expected. After a strong tremor in the year 1819, an event of similar strength was not expected to occur again for about 1,000 years. In fact, however, it was not even 200 years before the earth shook again with a comparable release of energy.

The great tsunami earthquake with its epicentre off the northwest tip of Sumatra and a magnitude of about 9.2 was also surprising in various ways. The tsunami triggered by the displacement of the seabed spread right across the Indian Ocean. Also, such an exceptionally high magnitude had not been expected at this particular spot. Although geological investigations on the coast of Central Sumatra had revealed indications of an earthquake with a magnitude of approx. 9 in the year 1833, the fact that the rupture spread from the 2004 epicentre over a distance of 1,200–1,300 km to the north did not concur with previous theories about the large tectonic setting of such giant earthquakes.

Higher and higher losses

The overall and insured losses from earthquakes have increased dramatically in recent decades. The reasons are primarily to be found in the general growth in population, the concentration of inhabitants and values in highly exposed cities, and in the growing use of modern, sometimes extremely vulnerable high-technology. This has resulted in maximum loss potentials reaching new orders of magnitude. A major earthquake in the Tokyo region like the one in 1923 would nowadays cause an overall loss of about US$ 1,000bn.

The problems facing a megacity like Greater Istanbul were made even clearer by the Izmit earthquake. Since 1990, the city has grown by about three million inhabitants. Triggered by the need to provide these people with housing, a permanent race with time has, almost inevitably, led to deficiencies in the quality of construction. This lesson from the Izmit earthquake is a universal one and was confirmed by the 2001 earthquake that hit Bhuj in the Indian state of Gujarat, a region currently enjoying a strong economic upswing.

The 1999 earthquake in Taiwan, on the other hand, clearly revealed the considerable defects that existed in the country's infrastructure, particularly as far as the necessary redundancy in the energy supply network is concerned. One of the country's key industries was disrupted when the quake hit the high-tech industrial park of Hsinchu. Electrical power for the park was supplied by a single transmission line and this was broken at a highly inaccessible location. As there were not enough emergency power generators in place to maintain the supply, production was interrupted for several weeks, resulting in serious shortages of semiconductor elements throughout the world. Business interruption accounted for 45% of the overall loss, an all-time high.

Insurance developments

Loss development has triggered more – though not enough – commitment to risk management and more use of alternative risk transfer. Within the last few years, various insurance pools have been set up for residential and small commercial risks, and earthquake insurance has increasingly been used in connection with obtaining mortgage loans. Loss adjustment procedures have had to be completely reconsidered, too. One of the main reasons for claims payments being so high after the Northridge earthquake was that the insurers were overtaxed by the more than 500,000 individual claims. In the light of this experience – and the obligation to make consumer-friendly settlements – private insurers limited the scope of their earthquake cover. This, in turn, led to the foundation of the California Earthquake Authority (CEA).

Events like Izmit and Düzce accelerated the foundation of the Turkish Catastrophe Insurance Pool, which has the aim of speeding up market penetration of earthquake insurance.
Likewise, Taiwan took action immediately after the events of 1999 and set up the Taiwan Residential Earthquake Insurance Pool. The event in Gujarat also resulted in the establishment of national loss prevention and reduction programmes.

Bhuj, India, 26 January 2001. The earthquake was one of the unexpected events, since the epicentre was several hundred kilometres from the plate boundary in the north of India.

Chi-Chi, Taiwan, 21 September 1999. Numerous apartment blocks collapsed. But the losses caused by incessant power outages were much costlier than those due to structural damage.

Table 1 Earthquake catastrophes from 1994 to 2006

Date	Region	Magnitude	Fatalities	Overall losses (US$ m)*	Insured losses (US$ m)*
17.1.1994	USA (Northridge)	6.8	61	44,000	15,300
15.2.1994	Indonesia (Sumatra)	6.8	215	170	
1.5.1994	Afghanistan (northwest)	6.3	160		
2.6.1994	Indonesian (Java)	5.9	238	3	
6.6.1994	Colombia (southwest)	6.4	171	36	
18.8.1994	Algeria (Mascara)	5.6	171		
4.10.1994	Japan/Russia (Kuril Islands)	8.1	12	100	13
28.12.1994	Japan (Honshu)	7.8	3	170	12
17.1.1995	Japan (Kobe)	6.8	6,430	100,000	3,000
30.3.1995	Afghanistan (northwest)		354		
13.5.1995	Greece (north)	6.6	26	450	
27.5.1995	Russia (Sakhalin)	7.4	1,989	100	
15.6.1995	Greece (Gulf of Corinth)	6.4	26	660	
30.7.1995	Chile (Antofagasta)	8.0	3	30	19
1.10.1995	Turkey (Dinar)	6.1	94	205	
3.2.1996	China (Lijiang)	6.7	309	500	
17.2.1996	Indonesia (Irian Jaya)	7.5	166	6	4
28.2.1997	Iran (Ardabil)	5.5	1,000		
1/2.3.1997	China (northwest)	6.0	2	110	
6.4.1997	China (northwest)	6.4	1	130	
11.4.1997	China (northwest)	6.6	9	560	
10.5.1997	Iran/Afghanistan	7.3	1,573	500	
26.9.1997	Italy (Assisi)	5.6	11	6,000	6
15.10.1997	Chile (north)	6.8	9	150	
10.1.1998	China (north)	6.2	50	285	
4.2.1998	Afghanistan (Rostaq)	6.1	4,600		
22.5.1998	Bolivia (Aiquile)	6.8	105		
30.5.1998	Afghanistan (northeast)	6.9	4,500	10	
27.6.1998	Turkey (Ceyhan)	6.3	144	550	1
29.11.1998	Indonesia (Mangole)	7.6	41	200	110
25.1.1999	Colombia (Armenia)	6.2	1,230	1,900	150
29.3.1999	India (Uttar Pradesh)	6.6	110	2	
17.8.1999	Turkey (Kocaeli, Izmit)	7.4	15,000	12,000	600
7.9.1999	Greece (Athens)	5.9	143	4,200	120
21.9.1999	Taiwan (Chi-Chi)	7.7	2,368	14,000	750
12.11.1999	Turkey (Düzce)	7.1	845	500	40
4.6.2000	Indonesia (Sumatra)	7.7	130	6	
6.10.2000	Japan (Tottori)	6.5		150	28
13.1.2001	El Salvador (San Salvador)	7.7	845	1,500	290
26.1.2001	India (Bhuj)	7.7	14,000	4,500	100
13.2.2001	El Salvador (San Salvador)	6.5	315	80	16
28.2.2001	USA (Nisqually)	6.8	1	2,000	305
24.3.2001	Japan (Hiroshima Prefecture)	6.7	2	500	128
23.6.2001	Peru (Arequipa)	8.4	115	300	50
3.3.2002	Afghanistan/Kyrgyzstan	7.4	100		
25.4.2002	Georgia (Tiflis)	4.7	6	350	
22.6.2002	Iran (northwest)	6.5	245	300	
31.10/1.11.2002	Italy (San Giuliano di Puglia)	5.8	29	300	
24/25/26.2.2003	China (northwest)	6.4	268	150	
1.5.2003	Turkey (Bingöl)	6.4	176		
21.5.2003	Algeria (Boumerdes)	6.8	2,200	5,000	
16.8.2003	China (Inner Mongolia)	5.4	4	165	
25.9.2003	Japan (Hokkaido)	8.3	1	180	50
22.12.2003	USA (Paso Robles)	6.5	2	200	40
26.12.2003	Iran (Bam)	6.6	26,200	500	19
24.2.2004	Morocco (north)	6.4	640	400	
23.10.2004	Japan (Niigata)	6.6	46	28,000	460
24.11.2004	Italy (Lake Garda)	5.3		250	
26.12.2004	South Asia/Indonesia	9.2	210,000	10,000	1,000
28.3. 2005	Indonesia (Sumatra)	8.7		1,700	
8.10.2005	Pakistan	7.6	88,000	5,200	5
23.2.2006	Mozambique	7.0	4		
27.5.2006	Indonesia (Java)	6.3	5,800	3,100	35
17.7.2006	Indonesia (Java)	7.7	670	2	

*Original values

Source: Munich Re, NatCatSERVICE, as at 31 December 2006

This list of earthquake catastrophes 1994–2006 follows on from the second review that appeared in the special issue of Schadenspiegel in 1994 and covered the catastrophes in the period 1984–1993.

Earthquake risk – Opportunities for the insurance industry

The global increase in demand – resulting from higher and higher losses – and the deregulation and liberalisation of the insurance markets offer the insurance industry new opportunities. Many countries are striving to transfer the state's currently high share of losses following natural disasters to the private sector. With solutions based on sound underwriting considerations and sensible pricing – ideally in conjunction with incentives for prevention measures – the cover of earthquake risk offers interesting business opportunities.

Conclusion

When we look back over events from the recent past to San Francisco's hundred-year earthquake in 1906, we see that risk management has not managed to keep pace with scientific and technological progress. To counteract the dramatically increasing claims load, we urgently need to rethink the situation – away from a reactive process of coping with catastrophes after the occurrence to a proactive policy of loss prevention.

Further information

Munich Re's Geo Risks Research unit has published a series of brochures and articles on this topic. The following selection may be ordered from our website at www.munichre.com or downloaded as a PDF file:

The Yogyakarta earthquake, in: Topics Geo, Natural catastrophes 2006, pp. 28–31.

The 1906 earthquake and Hurricane Katrina, 2006.

Kashmir quake claims 88,000 lives, in: Topics Geo, Annual Review: Natural catastrophes 2005, pp. 30–33.

The Niigata earthquake in Japan, in: Topics Geo, Annual Review: Natural catastrophes 2004, pp. 22–25.

Tsunami catastrophe in 2004 – Results of a loss inspection on the west coast of Thailand, in: Schadenspiegel 3/2005.

The Bam disaster in Iran, in: Topics Geo, Annual Review: Natural catastrophes 2003, pp. 33–37.

Earthquake rocks Taiwan's chip industry, in: Schadenspiegel 1/2001: pp. 22–31.

How to assess the earthquake risk, in: Schadenspiegel 2/2000: pp. 21–31.

The vulnerability of modern societies to catastrophes – The earthquakes of Northridge in 1994 and Kobe in 1995, in: Topics 2000 Millennium, pp. 97–103.

Large earthquakes 1994–2006

Author
Dr. Anselm Smolka, Munich

Northridge, USA, 1994

With an overall loss of about US$ 44bn and insured losses of US$ 15.3bn, the Northridge earthquake is to this day the biggest loss event in earthquake insurance history. It was caused by a fault below the earth's surface, a blind-thrust fault. It came as a complete surprise when, some months after the earthquake, damage was discovered on steel-frame structures, because they had hitherto been regarded to be relatively earthquake-resistant.

Kobe, Japan, 1995

The Northridge quake was followed exactly one year later by the largest urban earthquake catastrophe in economic terms since the 1923 event in Tokyo. One positive aspect was that the structures built after a revision of the building code in the year 1981 stood up to the earthquake very well on average. On the negative side was the lack of coordination between the local and national authorities handling disaster response.

Izmit and Düzce, Turkey, 1999

The earthquake in Izmit was a particularly extreme demonstration of what happens when the seismic building code is not properly observed. Just as worrying was the lack of preparation for this event since it was by no means unexpected. The Düzce earthquake, which occurred just three months later, was immediately linked to the Izmit earthquake. This subsequent earthquake was triggered by a concentration of tectonic pressure at the eastern end of the activated segment of the North Anatolian Fault.

Athens, Greece, 1999

The earthquake, whose focus was about 15 km north of the city centre, came completely unexpectedly. It was a further illustration of the fact that even earthquakes of a low magnitude can cause losses running into the billions if the construction methods are inappropriate or if building regulations are not complied with. The earthquake is a particularly good example of how the growth of cities affects the earthquake risk. A similar event just 20 years ago would hardly have caused noteworthy losses because of the city's much smaller spread at that time.

Chi-Chi, Taiwan, 1999

The combination of location and high magnitude involved in this earthquake came as a surprise to the experts. The occurrence probability of such strong earthquakes in this region was estimated to be once in 10,000–100,000 years. This event was particularly significant on account of the business interruption losses at some semiconductor factories in the high-tech park of Hsinchu.

Bhuj, India, 2001

The earthquake that struck Bhuj in the state of Gujarat was also an unexpected event and was also caused by a blind-thrust fault. One of its main features was the enormously large radius affected, with buildings being damaged even in Mumbai, almost 600 km away. 14,000 people were killed.

Moquegua, Peru, 2001

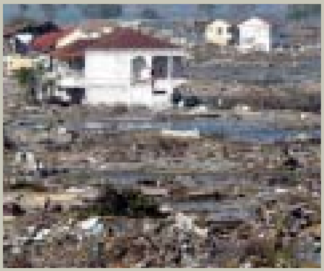
With a magnitude of 8.4, this was the strongest earthquake recorded anywhere in the world since the 1964 earthquake in Alaska. The earthquake and the tsunami it triggered hit the southern coast of Peru and northern Chile. It occurred in a zone classified as a "seismic gap" on the boundary between the Nazca and South American plates, which had last been the scene of an earthquake of similar strength in 1868. Another earthquake can happen at any time in the "gap" to the south.

Bam, Iran, 2003

The high death toll of about 26,000 must be attributed to the clay-brick construction methods in the old part of the city. The reinforced-concrete and steel-frame structures in the industrial area in the southeast remained for the large part undamaged. The fortress Arg-I-Bam, which had made a significant contribution to the region's income as a tourist attraction before the earthquake, was severely damaged.

Niigata, Japan, 2004

In 2004, the year of cyclones, this natural catastrophe in the north of the island of Honshu went by almost unnoticed by the media – in spite of being the year's most costly event with an overall loss currently estimated at around US$ 28bn. A large proportion of the loss was due to the destruction of infrastructure, including the Shinkansen rapid-transit railway system. Insured losses were low, however, since the damage occurred in a rural area. The infrastructure and the few industrial plants affected were either not insured at all or only on a small scale.



Indonesia, Southeast Asia, 2004

The second-strongest earthquake ever recorded occurred shortly before the end of 2004. Its epicentre was off the northwest tip of Sumatra and it had a magnitude of 9.2. The tsunami triggered by the displacement of the seabed spread right across the Indian Ocean, generating the worst human catastrophe since the 1976 earthquake in Tangshan, China.

Kashmir, Pakistan, 2005

Kashmir and parts of North Pakistan were devastated when they were struck by a magnitude 7.6 earthquake. The tremors lasted for 50 seconds, causing the collapse of some 200,000 houses and razing entire towns and villages to the ground. With 88,000 fatalities, approx. 200,000 injured, and more than three million homeless, the Kashmir quake ranks second only to the December 2004 tsunami as the worst natural catastrophe of the past decade. And the earthquake gave only a slight indication of the catastrophe potential of future earthquakes along the entire southern edge of the Himalayas.

Yogyakarta, Indonesia, 2006

A very similar message was communicated by what was only a moderately strong earthquake with a magnitude of 5.9 and an epicentre about 25 km south of the city of Yogyakarta in central Java. In view of the relatively low magnitude and the distance to the only large municipal centre Yogyakarta, the overall losses were extremely high at US$ 3.1bn. As in Kashmir, the essential reason for this was that the buildings were not sufficiently designed to cope with earthquakes.

Special topic: Earth – When the forces of nature become a danger

Volcanism – Recent findings on the risk of volcanic eruptions

Author
Dr. Anselm Smolka, Munich

Worldwide, around 550 volcanoes are classed as being active. Each year, between 50 and 65 of them erupt. The 1980 eruption of Mount St. Helens in the US state of Washington demonstrated the disaster potential of volcanoes. Since then, Munich Re has been considering the question how much risk volcanic eruptions involve.

Today, just as over 25 years ago, it is still true to say that – with the exception of extremely rare major meteorite impacts – there are no other natural events that can devastate such wide areas with comparable intensity and suddenness as volcanic eruptions. Their direct effects: lava, mud, and pyroclastic flows, glowing clouds, ash eruptions, and ash deposits. The indirect effects: climate change. The losses: besides the direct losses, disruption of air transport and shipping and crop failures.

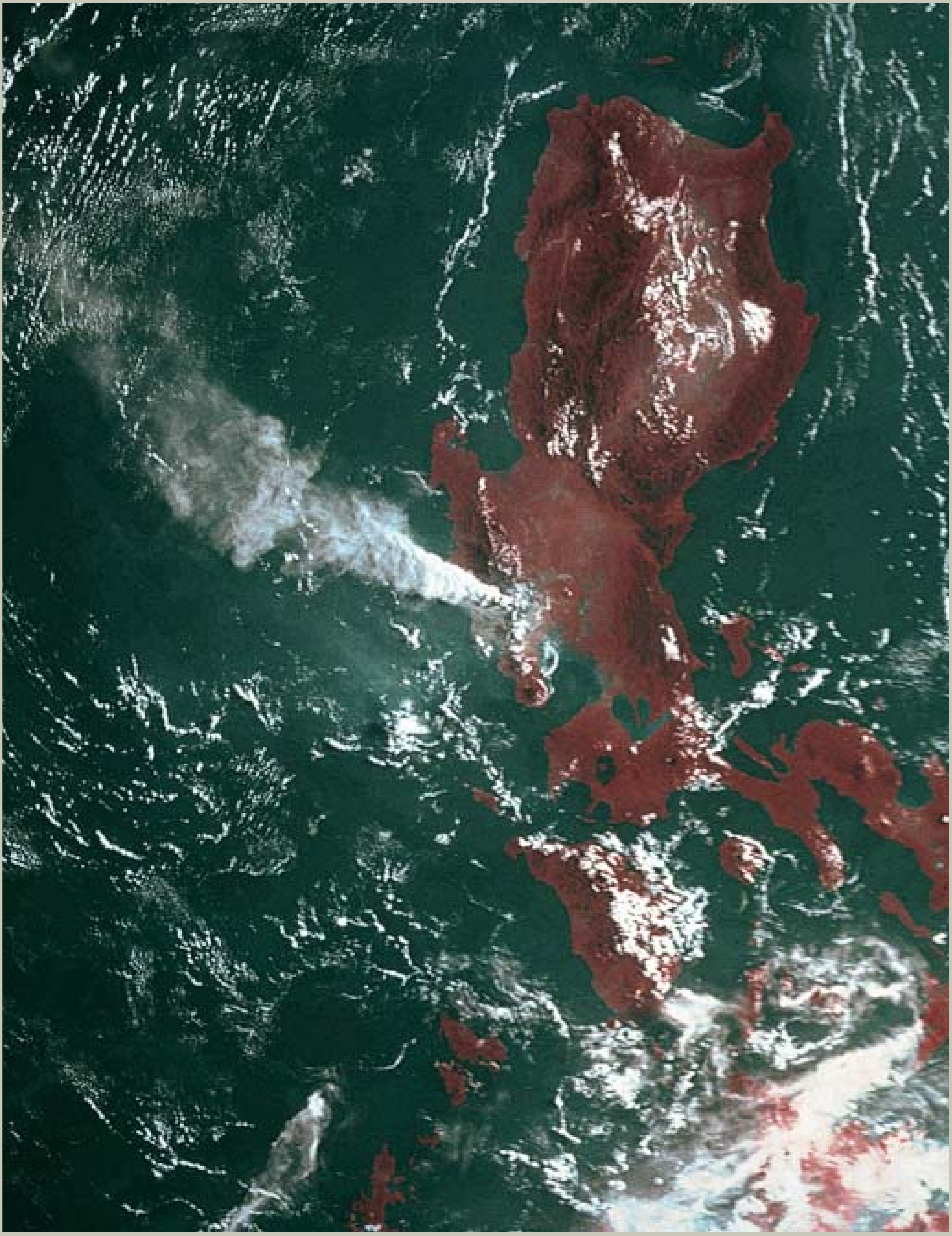
In the recent past, eruptions of Pinatubo (Philippines, 1991), Tavurvur (Papua New Guinea, 1993), and La Soufrière (Montserrat, 1995–97) have caused considerable insured losses, amounting to several tens of millions of US dollars in each case. The biggest eruption was that of Pinatubo, the climatic effects of which were felt worldwide. Aerosol-forming sulphur dioxide molecules got into the upper atmosphere, causing the average global temperature to fall by half a degree.

Cities at risk

Worldwide, around 500 million people live near volcanoes, the majority of them in cities. Auckland in New Zealand, for example, lies directly in a volcanic area. As a probabilistic exposure study shows, however, it is not the small volcanoes in the urban area that pose the main risk but the volcanoes situated some 200 km to the southeast and 260 km to the south of the city, some of them highly explosive – such as Mount Egmont (or Mount Taranaki in Maori). The main danger would come from ash deposits following an eruption.

Urban areas are also at high risk in Japan. Besides Tokyo, there are a number of cities with more than a million inhabitants like Nagoya, Kyoto, and Yokohama that are threatened. The area in the vicinity of Fujiyama, where 20 million people spend their holidays each year, would be particularly affected.

The area around Naples in Italy is also at risk. In past centuries, Vesuvius has erupted roughly every 30 years. If there were to be another eruption on the scale of the one that occurred in 79 BC, it is estimated that the property damage would run to around US$ 40bn, only a tiny proportion of which would be insured as things currently stand. Whether there is currently any risk though is disputed.



Satellite image of the ash eruption of Pinatubo in the Philippines, which erupted on 12 June 1991 after being dormant for 611 years. The following year, the average temperature worldwide fell by half a degree.

However, researchers have been getting more worried since 2001 when they discovered a 400-km^2 magma lake under Vesuvius which extends below the ground to beneath the hills of the Phlegraean Fields in northwest Naples. More than three million people live in this region, which means that the Phlegraean Fields probably pose a greater threat than Vesuvius itself. They are an example of a supervolcano, a popular-science term for volcanoes that have caused eruptions with a volume of 300 km^3 or more.

Supervolcanoes – The big danger?

They have no cone, are to be found under all continents, probably under the sea, too, and erupt very rarely. They are nevertheless one of the greatest natural hazards. Following an eruption, the roof of the magma chamber caves in, leaving a large basin known as the caldera. Supervolcanoes have very long periods of dormancy – tens to hundreds of thousands of years. The Geological Society of London produced a report on them for the British government which revealed that, besides the Phlegraean Fields near Naples, there is a second supervolcano in Europe, namely in the Eastern Mediterranean near the island of Kos. The last eruption of the Phlegraean Fields happened 35,000 years ago and was gigantic, with around 50 to 100 times the amount of material being ejected as in the 1991 eruption of Pinatubo. Supervolcanoes are also believed to lie beneath New Zealand, Kamchatka, the Philippines, the Andes, in Middle America, the United States, Indonesia, and Japan. The vast magma chambers lie at depths of 5–20 km. One such chamber beneath Yellowstone Park, for example, is twice the size of Luxembourg. Current satellite remote sensing observations show that parts of the caldera rise by several millimetres each year. An eruption would have unimaginable local and global consequences. However, the risk is not considered to be acute.

Effects of major volcanic eruptions on the global climate

A major volcanic eruption not only has an impact regionally; it also affects the global climate. The triggers of such changes are layers of aerosols that form following an eruption. These spread around the earth and reflect part of the solar radiation back into space, causing a fall in the earth's temperature.

Hitherto, effects on the global climate have not been the focal point of quantitative risk considerations. In 1992 – the year following the eruption of Pinatubo in the Philippines – the temperature worldwide fell by an average of half a degree Celsius. Damaging effects on the global climate have been documented before, however, particularly following the eruption of the Laki Rift in Iceland in 1783 and the eruption of Tambora on the island of Sumbawa (Indonesia) in 1815 – the biggest historical eruption, with around 10 times the volume of ejecta as from Pinatubo. However, it is not always possible to provide unequivocal proof of a direct connection between individual observations. When the events are considered in their entirety, however, a coherent picture definitely emerges.

Economic effects of volcanic eruptions

For a city like Tokyo, for example, with its 20 million inhabitants, a volcanic eruption would be catastrophic. When Fujiyama last erupted just under 300 years ago – in December 1707 – ash rained down on the city for two weeks, even though it lies 100 km away. If it were to erupt again, public life would grind to a halt.

Etna, the biggest volcano in Europe, likewise caused enormous damage when it erupted in 2001 and again in 2002/03. In 2002, the ash rain alone caused economic losses of around €800m.

Eruptions like Laki and Tambora not only produce direct material losses; they are also likely to have a disruptive effect on air traffic and shipping and lead to immense crop failures. According to forecasts by scientists at the Geological Society of London, agriculture would be impossible in many places. Crops will even be destroyed by a layer of ash just 1 cm deep.

Another scenario has also attracted considerable attention in recent years: if the west flank of Cumbre Vieja on La Palma were to break off as a result of the volcano erupting, this would cause a tsunami. The tidal wave would have a massive impact on the Canary Islands and, to a lesser extent, on the southwest coast of the Iberian peninsula and the northwest coast of Africa. However, more recent findings have toned down the initial forecasts on the propagation of the wave. Research has revealed that the height of the wave on the other side of the Atlantic would reach significant levels only in the northeast of South America.

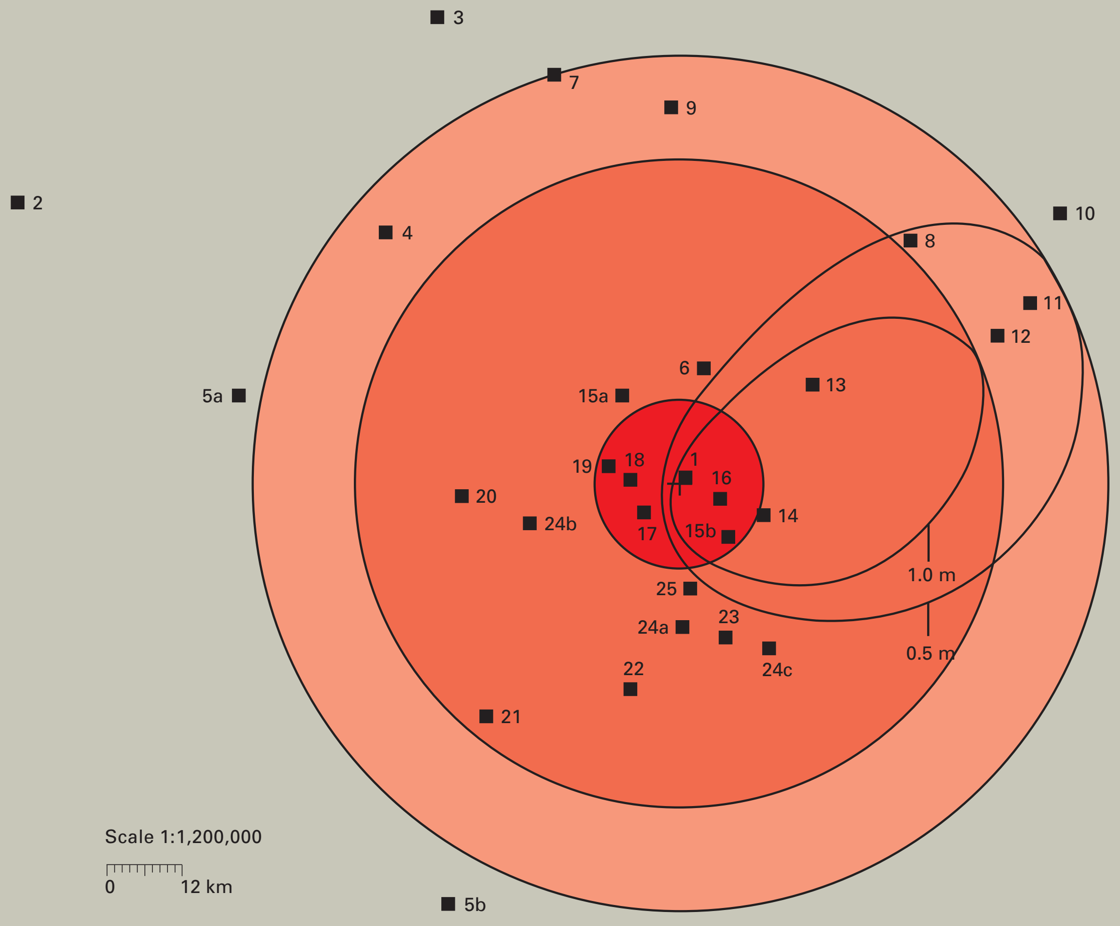
Simulation models

An international team of volcanologists and meteorologists under the direction of the Max Planck Institute for Meteorology in Hamburg and GEOMAR (Research Centre for Marine Geosciences) in Kiel studied how volcanic activity affects the climate. The aim was to produce a computer simulation of just what gets into the upper atmosphere. They succeeded in designing a numerical model that simulates the development of the eruption cloud and its interaction with the environment. ATHAM (Active Tracer High Resolution Atmospheric Model) is recognised in specialist circles, and many volcanologists worldwide have adopted it, one reason probably being that, with previous models, each type of particle had to be calculated separately – which was time-consuming and mostly ineffective.

Fig. 1 Examples of major cities situated near to active volcanoes

The cities are shown in terms of their distance from and direction to the respective volcano located at the centre of the diagram. Some cities are exposed to roughly the same threat from several volcanoes and are shown more than once.

The two outer zones mark the extent of a 0.5 or 1 metre covering of ash in the event of an eruption of the order of magnitude of the Krakatau eruption of 1883. The two isolines (on the right) represent the area actually affected, taking as an example the eruption of the Taupo volcano in New Zealand, which happened in around 130 AD. The prevailing winds mean that the ash does not spread symmetrically in a circle. The inner zone indicates the approximate extent of the area that, depending on a volcano's activity, can be affected by phenomena like lava flows, mudflows, and glowing clouds.



1 Auckland (Auckland volcanic field)
2 Vancouver (Mt. Baker)
3 Seattle (Mt. Rainier)
4 Tacoma (Mt. Rainier)
5 a, b Portland (Mt. Hood, Mt. St. Helens)
6 Mexico City (Xitli)
7 Surabaya (Ardjuno-Welirang)
8 Semarang (Sundoro-Sumbing)
9 Manila (Taal)
10 Tokyo (Fujiyama)
11 Kawasaki (Fujiyama)
12 Yokohama (Fujiyama)
13 Guatemala City (Agua Volcano)
14 San Salvador (San Salvador Volcano)
15 a, b Managua (Masaya-Nindiri, Apoyeque)
16 Quito (Pichincha)
17 Arequipa (El Misti)
18 Kagoshima (Sakurajima)
19 Naples (Vesuvius)
20 Nagasaki (Unzendake)
21 Shizuoka (Fujiyama)
22 Yogyakarta (Merapi)
23 Catania (Etna)
24 a, b, c San José (Barba, Irazú, Poás)
25 Bandung (Tangkuban Prahu)

A string of craters extends along the Laki Rift in Iceland. The probability of an eruption like the one in 1783 is put at once in around 1,000 years.

ATHAM, on the other hand, analyses the particle ensemble as a whole and also takes account of external factors such as ambient temperature. The application has a relatively simple structure, consisting of a stable core calculation that can be supplemented as required with single, individually adjustable modules. Up to now, for example, calculations have been based on a simple cloud model, whereas ATHAM makes it possible to incorporate a more sophisticated cloud model.

Frequency of volcanic eruptions

The effects of large volcanic eruptions require the occurrence probability to be looked at not only on a local basis but also globally. Unfortunately, major eruptions have not been fully documented – either in historical or in geological terms. Using statistical methods and based on data available so far, experts have calculated a worldwide occurrence probability of once in 500–1,000 years. It applies with respect to the magnitude of the Tambora eruption of 1815. In order to be able to arrive at more precise values of the occurrence probability in future, Munich Re is currently supporting a research project under the overall control of the Department of Earth Sciences at the University of Bristol (UK). The aim is to extend the database for major eruptions from the current 2,000 years to 10,000 years.

As part of these statistical frequency estimates, a new scale for the strength of volcanic eruptions was also developed: volcanic magnitude, which is based on the mass of the volcanic products ejected in an eruption. The volcanic explosivity index (VEI) used hitherto is based on volume. The problem is that the density of volcanic rock can differ, which means that the volume bears no unequivocal relationship to the mass. Consequently, the VEI does not give adequate consideration to the different types of eruption. The definition of mass is always the same, however. Volcanic magnitude therefore creates a uniform data basis for further research. For each full step on the volcanic magnitude scale, the mass increases by a factor of ten. The Tambora eruption of 1815 has a magnitude of 7– on this scale. The biggest eruption in the last 100,000 years – that of Toba in Indonesia – reaches a magnitude of 8+. The event in the Phlegraean Fields 35,000 years ago would have had a magnitude of 7+.

Volcanic eruption – An insurable risk?

In principle, volcanic eruption is an insurable risk. Apart from a few exceptions, however, the rarity of loss occurrences means that the technically necessary rate is marginal. Volcanoes like Vesuvius are intensively monitored by measuring instruments – an eruption would therefore hardly come as a surprise. However, it would not be possible to estimate the strength of an imminent eruption. Any action taken in response to an advance warning – in other words, an evacuation – would constitute a huge logistical challenge, as more than a million people live within 10 km of the crater.

However, volcanic eruptions can also become global catastrophes. An eruption like that of the Yellowstone volcano 630,000 years ago would exceed the limits of insurability. At that time, huge areas of North America were covered in ash. The scale of the damage is unimaginable.

So far, the insurance industry has not dealt systematically with such extreme events, including those involving other natural hazards. Munich Re will therefore continue to support projects that make it possible to better assess such risks in the future.

Volcano monitoring

Mount St. Helens and Vesuvius are two of the best-monitored volcanoes in the world. Thanks to modern equipment, the smallest changes can be registered.

Earthquake station This is the cornerstone of volcano monitoring. It records the breaking and creaking of rock that is triggered when magma forces its way upwards.

GPS sensors can detect changes in the ground surface. When magma presses against the crust, the ground bulges, changing the location of the sensors. Inclinometers also record changes in topography.

Radar interferometry Two radar images taken at different times are superimposed, producing an interference pattern that shows with centimetre accuracy where the earth's surface has moved.

Chemical analyses of gas emissions give clues to the status of any activity.

Infrared cameras detect heat sources.

Nevertheless, particularly in poorly developed countries, funds for volcano monitoring are lacking. El Misti in Peru, for example, is not monitored at all, despite the fact that Arequipa, the country's second largest city, lies at its foot. In an emergency, the US Geological Survey (USGS) offers help – if required, equipment can be available within ten hours.

Further information

Coles, S. G., Sparks, R. S. J.: Extreme value methods for modelling historical series of large volcanic magnitudes, in: Mader, H. M., Coles, S. G., Connor, C. B., Connor, L. J. (Ed.): Statistics in Volcanology, 2006.

Gisler, G., Weaver, R., Gittings, M. L.: Sage Calculations of the Tsunami Threat from La Palma, in: Science of Tsunami Hazards, Vol. 24, No. 4 (2006), pp. 288–301.

Magill, C. R., Blong, R. J., McAneney, K. J.: VolcaNZ – A volcanic loss model for Auckland, New Zealand, in: Journal of Volcanology and Geothermal Research 149 (2006), pp. 329–345.

Mason B. G., Pyle D. M., Oppenheimer C.: The size and frequency of the largest explosive eruptions on Earth. Bulletin of Volcanology 66 (2004), pp. 735–748.

Munich Reinsurance Company (publ.): Volcanic Eruption – Causes and Risks, 1983.

Sparks, S. & Self. S. et al.: Super-eruptions: global effects and future threats. Report of a Geological Society of London Working Group, 2nd Edition, 2005.

Clay soils dry out especially in hot summers – they shrink and sink, which can cause damage to buildings.

Special topic: Earth – When the forces of nature become a danger

Subsidence – When the ground sinks

Author
Dr. Anselm Smolka, Munich

It announces itself with jamming doors and windows, or diagonal cracks in buildings. We are talking about a kind of ground settlement that occurs above all in areas where clay soils predominate and in England is known as "subsidence". In southern England and France, this natural hazard has cost insurers a great deal of money in recent decades. For these soils can shift and sink by different amounts.

The ground can subside or collapse for various reasons. On the one hand, when underground cavities form – as in karst areas. Here, carbonic acid in rainwater and groundwater dissolves the rock-forming mineral calcite out of the limestone bedrock, thus giving rise to cavities (also known as "sinkholes"[1]), which may unexpectedly cave in under the weight of massive building developments or in some cases quite spontaneously. On the other hand, areas in which coal, oil, or gas is extracted or groundwater is removed from the ground may also subside.

Another cause of subsidence is that clay soils containing so-called swelling clays will shrink if there are prolonged dry periods. For insurers, this type of damage is a particularly big problem, as it mostly affects wide areas in which there is a concentration of values (buildings). The direct and very visible effects of subsidence arising from an area's geology are cracks in buildings. Especially following dry summers, the accumulated losses can lie in the three-digit million range.

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[1] Sinkholes – When the ground suddenly collapses, in: Schadenspiegel 3/2005 Special feature issue: Risk factor of water.

The ground sinks when water is removed

Why hot summers can have serious consequences becomes clear from the chemical composition of clays. One of the minerals they contain is montmorillonite, which can increase its volume tenfold when it absorbs water. As the weather is rather damp in England, for example, damage occurs there when water is abstracted: the ground shrinks and subsides. In predominantly dry areas, on the other hand, water causes the ground to swell – and then it lifts. Because of the usually smaller accumulation of values in such areas, however, the losses that can occur in such cases are far smaller than those that result from subsidence.

Losses of over €8bn

Subsidence damage arising from the local geology is typical of southern England. Subsidence was included in buildings insurance in 1971, at no extra premium charge, following pressure from lobbyists. The exceptionally dry summer of 1976 then brought insurers a rude awakening. It was initially interpreted as a hundred-year event, but the claims payments subsequently continued year after year. In 1991, the cost of claims peaked at €800m. All in all, since 1976, buildings insurers have paid out more than €8bn. Insurance companies in the UK responded by introducing premiums and deductibles that are dependent on the geographical location – with the result that highly exposed properties are hardly insurable any more.

In France, subsidence is insured through the state CatNat Pool. When this natural catastrophe insurance (“L’assurance des catastrophes naturelles”) was first introduced, lack of claims experience meant that the risk was not properly rated. Claims for subsidence now account for a substantial proportion of the annual claims burden.

How can subsidence be avoided?

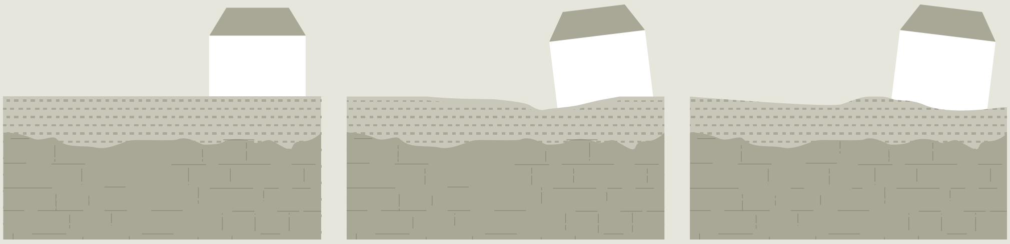
In most cases, subsidence in areas with clay soils only becomes dangerous when buildings are badly designed and executed. Damage can be prevented with foundations and cellars. In southern England and France, it is not usual to build cellars under buildings; as a result, subsidence is a big problem there. This is different from the situation in various regions of northern Germany where, despite similar geological conditions, such damage rarely occurs – here it is usual for houses to be built with cellars.

It is very costly to put buildings right afterwards. In England, the experience of the hot summer of 1976 led to changes in the building regulations, though these were only recommendatory in nature. Insurers there are also very heavily involved in loss prevention and give their customers advice. In France, they are thinking about limiting subsidence cover (within natural hazards insurance) because of the negative claims experience.

Drier summers – More frequent subsidence

Global warming and its regional characteristics will no doubt further aggravate the problem in the future, the main reason being that the probability of dry summers in mid-latitudes is increasing. Despite differences of opinion in individual cases, the risk of subsidence arising on account of an area’s geology can be assessed quite well on the whole. As a result, it is also possible to carry out targeted loss prevention. Munich Re supports insurers’ initiatives to raise their customers’ awareness of the risks and to advise them on ways of avoiding damage.

Fig. 1 Subsidence and heave of clay soils



Weather constant – the ground hardly changes.

During dry periods, the ground shrinks.

After rain, the ground swells.

Source: Geo Risks Research

One of the minerals that clay soils contain is montmorillonite, which can increase its volume tenfold when it absorbs water.

Ore stone slid over 450 m – the length of four-and-a-half football pitches – down to the floor of the mine. The destructive force of the material was immense.

Slope failure in open-pit mine

Author
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Around 2.5 million tonnes of copper and gold ore and waste material slid over 450 m in one of the biggest copper and gold mines in the world. Damage to slopes and benches in open pits is usually not covered under all risks policies for mining operations – but damage to machinery and equipment is.

When the debris slid down in this mine, five heavy-duty trucks (HDTs), one hydraulic shovel, one drill rig, and auxiliary mining equipment were destroyed. Eight miners lost their lives and another 13 were injured.

The mine is located on a Pacific island at a height of 2,900 – 4,300 m above mean sea level, approx. 120 km inland. It lies just south of the Equator where the climate is tropical with heavy, driving rain. It represents the second biggest copper deposit and the biggest gold deposit in the world. In 2003, copper production (in concentrate) accounted for around 7% of the world's production. Following the incident, the price of copper on the London Metal Exchange (LME) rose by 30% overnight.

Extent of the loss

Copper and gold ore and waste had come loose roughly in the middle of the southern slope of the open pit. The debris slid right down to the bottom of the pit and destroyed five HDTs with a payload of 240 t, one hydraulic shovel, and one drill rig. Three other HTDs and other mining machines found their way out of the mine blocked, as the access roads were buried or destroyed. Workers had to be rescued from these cut-off areas by helicopter. Slope failures of this size are quite rare, and the number of fatalities is unusually high for open-pit operations.

Cause of the loss

The rock on the southern edge of the open pit was friable. The slope angles had originally been created with a safety factor to cater for these difficult geological conditions. As operations changed, however, and the competence of the rock deteriorated – which was not apparent from the outset – the slope angles became steeper, thus increasing the risk of a failure.

HDTs were at the mercy of the falling material. One of the colossal trucks – 5 m high and more than 10 m long – lies in ruins.

Movements in open-pit slopes are closely monitored, in particular in areas with difficult geology. In the days shortly before the slope failure, geologists discovered a ground movement on the southern slope, but this was not considered to be exceptional. Immediately before the loss event, however, the situation was aggravated by rainfall that was unusually heavy, even for this region – a factor that further contributed to the material slipping.

Insurance aspects

Damage to open-pit slopes and benches is generally excluded in all risk policies for mining operations. The restoration of damaged slopes and benches is therefore not covered either. However, this exclusion does not apply to machinery and equipment located within the mine. The destroyed mining machines were therefore indemnifiable, as was the business interruption loss deriving from the destruction of this machinery.

Landslide – Hydropower plant construction site in danger

Authors
Gerhard Loos, Munich, and Germán Selgas, Buenos Aires

Following a landslide, earth masses piled up to form a natural dam, 150 km away from a hydropower plant construction site. When this finally eroded, an avalanche of stone and mud with a discharge rate of up to 1,000 m³/s plunged down the valley and onto the construction site, burying construction machinery and material.

A 137-m-high and 620-m-long concrete-faced rock-fill dam (CFRD) and a 1,500-m-long headrace tunnel needed to be built for a hydropower plant at the foot of the Argentinian Andes. The tunnel was to conduct the water from the reservoir to a power plant (likewise part of the construction project) with two Francis turbines (63 MW each).

In order to keep the section of the valley dry for construction of the dam, a cofferdam was constructed, together with a 650-m-long tunnel, which diverted the river. This diversion tunnel would later serve as the bottom outlet of the reservoir.

Risk of flooding threatens from a distance of 150 km

During construction work on the main dam, a slope collapsed 150 km upstream in a completely uninhabited part of the High Andes. The earth masses filled the valley floor, thus forming a natural dam. When the summer snowmelt began, water was retained above the dam and – as it was later discovered – built up to form a natural lake some 2.5 km long and almost 300 m wide, with an estimated volume of 40 million m³. The water flowed over the crest and eroded the dam. The water washed the embankment away at an increasing rate. With flow rates up to over 1,000 m³/s, the lake drained away, the water masses eventually taking the entire embankment with them. An avalanche of stone and mud flowed down the valley towards the construction site for several hours at a speed of around 20 to 30 km/h. It caused damage in one small village and also brought down bridges. Warnings about the imminent danger were relayed to the construction site by radio from the village. Because time was short, however, they only managed to rescue people and vehicles that could be moved quickly.

Avalanche of stone and mud reaches the construction site

Initially, the cofferdam held the water masses back. As the diversion tunnel was only designed for a maximum flow rate of 660 m³/s, however, it was not able to carry this large quantity away. The water quickly rose and – as had already happened before, 150 km upstream – eventually eroded the cofferdam and flooded the construction site as far as the main dam, which was high enough to hold back the water.

Construction machinery and material destroyed

Cranes, injection equipment (for sealing and consolidating the dam foundation), and concrete mixers swirled around in the water, while containers that had been used as offices or contained measuring equipment sank.

Once the cofferdam had been rebuilt and the construction site pumped dry again, a desolate picture emerged: a blanket of sludge about 6 m deep containing debris deposited by the river and the remains of the cofferdam had buried equipment and material. In the course of the clean-up operations, which lasted for several months, around 120,000 m³ of mud and rubble was removed, and attempts were made to save some of the machinery and equipment. Only very few items of equipment could be repaired, however.

The strong flow of water also caused enormous damage to access roads. The diversion tunnel was also damaged, though just how badly will only become apparent once impounding of the reservoir starts, as until then the river has to flow through the tunnel.

Repairs to the construction site and other repairs cost several million US dollars and were covered by a CAR policy. However, because the damage considerably delayed completion of the power plant, the monetary loss was much greater (around US$ 30m). These costs were not covered, as there was no advance-loss-of-profits (ALOP) policy.

A still partially buried crane in front of the main dam. As the machines used in dam construction are technically sophisticated and expensive, the loss is enormous in most cases.

The remains of a diesel generator – completely deformed by the strong flow of water and debris.

Built on peat

Author
Winrich Krupp, Munich

Small cracks in asphalt, sunken kerbstones – these were the first harmless cases of damage on a new development. But then other, more major damage occurred until, finally, all the rehabilitation plans failed.

Subsoil investigations had already indicated that the building ground would give rise to problems. For, not very far down, a layer of non-bearing peat up to 8 m thick ran like a ribbon through the new housing estate. It had been built in an attractive, sunny location along a slope on the outskirts of a town in the West Midlands, England. More than 40 semi-detached and terraced houses were to be built in three construction phases. The construction company made provision for this and engaged a firm of engineering consultants to develop a plan that would guarantee safe development of the site.

Construction phases 1 and 2

The houses in phase 1 were built without any problems as they were on what was (still) stable ground. For the buildings in phase 2, however, extensive foundation work had to be carried out: the engineering consultants' recommendations were followed, and it was decided to build the houses on pile foundations. Numerous bored piles were used to reach bearing layers of soil. The new buildings in phase 2 could then be constructed, seemingly without problems, on concrete joists that covered the piles. Soon afterwards, the semi-detached and terraced houses were completed, together with garages and drives and access roads, kerbstone edgings were laid, and fences, gates, and patios were installed. The first buyers moved into their new homes.

Things start jamming, sinking, and breaking

It was not long before the builder began to receive the first complaints: garden gates that were jamming, kerbstones that were going crooked and sinking, access roads that were developing cracks. Although attempts were initially made to rectify these supposedly minor defects, it soon became apparent that such repairs only remedied the problems for a short time. The problems not only recurred, but in addition more and more houses were being affected.

It soon became clear that the problem was very serious. The analysis of the damage produced a surprise for everyone concerned: although the right safety measures had been taken to give the houses in phase 2 the right foundations, no-one had thought to adapt the entire infrastructure of this construction phase to the foundations employed.

For around the houses, which stood on secure pile foundations, the ground was sinking. Drains, water pipes, gas pipes, and power lines were shifting, pipes were breaking open and cracking. On garage driveways, steps were appearing that could not be negotiated with "normal" cars. House entrances that were once level with the ground needed extra steps.

A fence protects the empty houses on the new housing estate. Massive damage occurred because the development plan for the peaty soil did not go far enough.

Phase 2 house, constructed on pile foundations. The surrounding ground became compacted, however, and subsided.

The reason for this subsidence was the peat layer, which was slowly and inexorably compacting under the weight of the development. The effect was further aggravated by the additional weight of the excavated material that had been used to fill the site to a depth of up to 2 m.

Property damage and unsaleable houses

Because of the damage to property, the restricted use of the houses, and the potential damage to health caused by intolerable stress, indignant homeowners brought pressure to bear on the developers. Vacant houses could not be sold – even homeowners who were not directly affected reported losses in value and pointed out that their houses were probably unsaleable. The local authority ordered safety measures to prevent empty houses from being vandalised, and the area had to be kept under constant supervision in order to avoid accidents and allow defects to be repaired.

Rehabilitation plans fail

Numerous rehabilitation plans were developed – and then rejected again. The plans failed for several reasons, but mainly because it was doubtful whether the measures were technically feasible and would be permanently successful, or because the costs were disproportionately high.

Despite every effort, the only remaining option was to halt further development, secure the site, and buy back the houses that had already been sold.

While attempts were made to find an acceptable rehabilitation plan that would keep everyone happy, the question of insurance cover and liability also needed to be examined. This involved considerable time, effort, and expense, because the indemnification under the developer's and the contractor's CAR policies, which also covered consequential loss arising from faulty design, had to be clearly delimited from various liability covers – especially the engineering consultants' liability policy.

In conciliation proceedings prompted by the action taken against the responsible engineering consultants, it was in fact possible to recover a substantial part of the claims payments made under the CAR and liability covers. Full restitution was refused, however, mainly because of the construction company's presumed contributory negligence.

On garage driveways, steps appeared that could not be negotiated with "normal" cars.

Drains, water pipes, gas pipes, and power lines shifted and cracked.

Deformation and collapse of laid pipeline

Author
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If a pipeline is deformed[1] by more than 2% shortly after the trench is backfilled, it usually means that the quality of the laying process was not adequate or even that the design was defective.

The insured risk was a water pipeline forming part of a network connecting three water reservoirs. The basins receive water from several rivers. The aim of the project was to guarantee the water supply for a province on the central coast of Ecuador. The region has an extremely dry climate with rain only during the wet season of the year from January to June. What is more, due to a central mountain range that stretches from north to south and rises to an elevation of 900 m in some parts, it does not receive any water from the thaw in the mountains of the Andean Cordillera.

The original plan envisaged the interconnection of the reservoirs by means of three diversion tunnels. Construction work began in the mid-1990s. The first of the tunnels was almost completed when work had to be suspended due to excessive rainfall and flooding of the area caused by El Niño (which was very pronounced in 1997/98). El Niño was also responsible for a thick bed of sediments carried by the local river accumulating at the inlet shaft and blocking the flow of water into the tunnel.

Pipeline replacement of diversion tunnel

Dredging out the sediments would only be a temporary solution due to problems of inlet shaft blockages. The permanent solution was to lay a pipeline 1.4 km in length and 3.5 m in diameter on the river bed.

The project started with the construction of a provisional dam, a spillway, a retention dam, a water intake, and access roads. Then the pipeline was laid in a 4-m-deep trench on the left bank of the river. It ran upstream from the intake tower under the dam, crossed the river after about 1.3 km, and then joined the original tunnel inlet.

Inspection revealed initial deformations

Initially, work progressed without difficulty. Backfilling of the pipe trench was more or less complete when an inspection revealed that the pipeline was deformed at various locations. Since the pipeline was due to be handed over, the deformations had to be examined and remedied as quickly as possible. In order to prevent the pipeline from collapsing, an independent consultant appointed by the construction company recommended the installation of internal steel reinforcements on the section of pipeline under the dam and the section near the riverbed crossing. Furthermore, a retention wall was recommended to be

Pipe segment distinctly deformed, unable to support the pressure of the backfill material.

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[1] Deformation means a change in the vertical diameter, usually expressed as a percentage of the pipe's diameter.

installed where the pipeline changed direction (at a bend) in order to cushion the pressure of a rock face. Remediation work was still in progress when the project was handed over.

The collapse

The pipeline was still being reinforced at critical locations when it collapsed at the bend. This raises the question whether the entire pipeline had also collapsed. Divers were dispatched to investigate. The divers entering from the dam side could only reach the section of pipeline that had already been reinforced. The divers coming from the shaft side discovered that the pipeline had collapsed some 500 m from the entrance and could not proceed any further. This meant that the largest section could not be investigated in this way. In order to overcome this, a plan was developed for six shafts, which would give the divers access at several points, but due to difficulties of implementation, it was abandoned. Measurements using a penetrometer (which gauges the soil density) revealed that the pipeline between the dam and the collapse location and from there to the shaft entrance was so badly deformed that it would have to be replaced.

Extent of damage

- Damage to the 12.5-mm pipeline under the dam: deformation to be repaired by means of reinforcement
- Damage to the 9.5-mm pipeline and the trench running as far as the collapse: to be replaced with a stronger pipe
- Damage to the 12.5-mm pipeline and the trench in the bend area and crossing: to be replaced with a stronger pipe

Cause of loss

An international consultant on pipeline systems and a specialist in the field of geotechnology were appointed to investigate the cause of the loss. Their reports both came to the same conclusion: the deformation of the pipeline was due both to serious omissions in the construction phase and to errors in the design of the pipeline itself. The problem was explained in more detail as follows: if a pipeline has thin walls, careful attention must be paid to the external forces exerted upon it – by the backfill, for instance, and the transition from dry to wet weather conditions during construction, which may lead to considerable changes in the characteristics and structural integrity of backfill material.

Insurance aspects

The insured construction company filed a claim for roughly US$ 18.5m, corresponding to the costs of repair. Since the EAR cover had ceased to apply once the project was handed over, the loss occurred during the extended maintenance period. However, the policy contained an endorsement stating that only the costs of reinstating the pipeline to its defective condition (i.e. the condition immediately prior to the loss) were indemnifiable. Improvements to the design and related costs were excluded. A meticulous examination was carried out to determine how much of the claim related to costs for design improvements and alterations. As a result of this investigation, the claim was reduced by a number of items including the following: costs relating to increasing the thickness of the pipe once the trench was filled, raising the number and size of stiffeners and filters in order to achieve sufficient stability, and reinforcing the trench slopes. Lengthy negotiations were necessary before the parties involved came to an agreement. The loss was finally settled at around US$ 12m.

The pipeline had to be re-laid. One of the design improvements: replacement with a pipe with thicker walls.

A further improvement: the trench was reinforced with concrete on the slope side, thus reducing the pressure on the new pipeline.

Highway bridge collapses

Author
Lorenzo Celis, Caracas

At the beginning of 2006, Viaducto Uno, a road bridge on the main artery between Caracas and the port and airport collapsed along a stretch of 300 m and fell into a ravine 61 m below.

300 m long, 21 m wide, and 61 m high, this was once the fifth largest concrete arch bridge in the world. But there had been massive displacement on the southern slope and nothing could prevent the bridge from collapsing. This process had intensified in recent years and had impaired the stability of the buttress, the foundations of the side piers, and especially the foundations of the arch and the main pier.

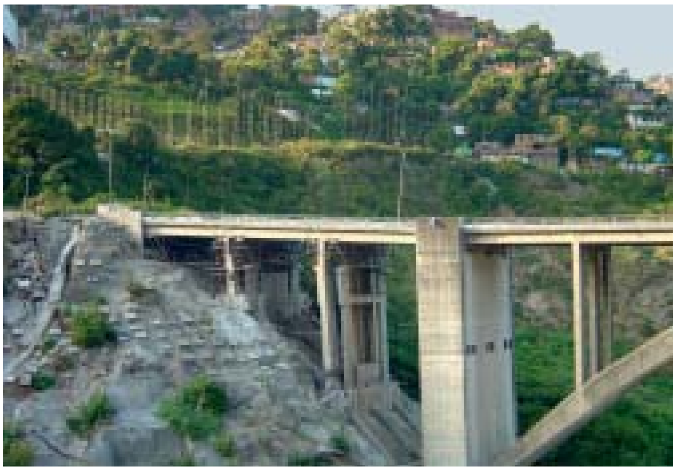
Spanning the Tacagua River, the bridge was part of the 34-km highway that links Venezuela's capital Caracas with La Guaira, the country's main port, and Maiquetía Airport. Built in the early 1950s, its arch structure consisted of three parallel elements with two joints and a clear width of 154 m.

Considerable damage had already begun appearing in the 1980s. Large cracks formed at various places because the slope was shifting and earth was sliding downwards.

The movements were due to what is known as the Tacagua fault. The massive displacement at the beginning of 2006 may also be attributed to this geological feature. Another factor was the lack of a waste-water system so that in the course of time the soil had become waterlogged and thus increasingly unstable.

Investigations revealed that the horizontal movement of the arch foundations was less than the movement of the piers, thus exposing the carriageway to high levels of stress. Also, the distance between the arch foundations and the arch girders gradually decreased, thus deforming the bridge structure and raising the keystone. All attempts to save the bridge failed.

A new bridge has already been built in accordance with the recommendations of geological reports. It has concrete piers and a steel superstructure. And the viaduct is already open to traffic.



Viaducto Uno at the beginning of 2006: the piers were still supported by scaffolding ...

… but nothing could be done to avert the collapse.

Major losses and natural catastrophes in 2006

Many major losses and natural catastrophes occurred again in 2006. Here is a selection of the significant ones.

January–March, Europe
Winter damage

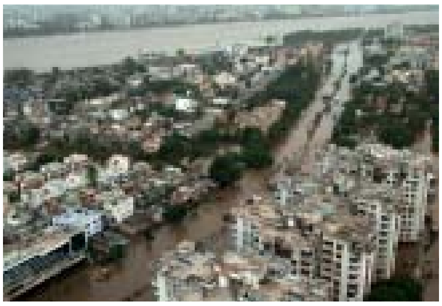
20 March, west coast of Australia
Cyclone Larry

21 March, Yemen coast
Fire on container ship *Hyundai Fortune*

5 May, Belgium
Fire in a hangar

29 May, Indonesia
Mud volcano

22 June, Germany
Conflagration in a steelworks



July–August, India
Monsoon floods

12 October, Lithuania
Fire in a refinery

30 November–5 December, Philippines, Vietnam
Typhoon Durian

Date	Region	Loss event
January–March	Southern and eastern Germany, large parts of Austria, the Czech Republic, and Poland	Winter damage Extreme falls of snow result in massive snow pressure damage to buildings and installations. The overall loss in Europe for the 2005/2006 winter is around US$ 1bn, half of which is insured.
20 March	West coast of Australia	Cyclone Larry – with wind speeds of up to 290 km/h – causes losses amounting to US$ 1.3bn near the city of Innisfail, Queensland, and in the neighbouring region. The cyclone is even stronger than Cyclone Tracy, which almost completely destroyed the city of Darwin, Northern Territory, in 1974.
21 March	Yemen coast	Fire breaks out on the container ship *Hyundai Fortune* (built: 1996, size: 64,054 GT, length: 275 m, width: 40 m). The cause is still unclear. The insured loss to the vessel and its cargo is expected to be as high as US$ 300m.
5 May	Belgium	A fire in a hangar at Brussels Airport destroys a number of aircraft, including an Armavia A 320 (EK 32010), an Armenian Airways A 320-200 (EK 32001), a Hellas Jet A 320-232 (SX-BVB), and a Belgian Air Force C-130 Hercules.
29 May	Indonesia	Mud volcano The exploratory borehole of an crude oil company hits an underground reservoir of mud. The subsequent eruption floods more than 5,000 dwellings and numerous other buildings including textile factories. Experts are of the opinion that the mud volcano may remain active for years.
22 June	Germany	Conflagration in a steel works The fire originates in the cold rolling mill. It is the largest insured industrial loss in Germany to date.
July–August	India	Monsoon floods plunge the 15-million-inhabitant metropolis of Mumbai and the surrounding area into chaos. Around 1,000 people are killed in these two months.
12 October	Lithuania	Fire in a refinery Released hydrocarbons ignite and explode because the outlet pipe of the vacuum distillation unit is corroded and leaking.
30 November– 5 December	Philippines, Vietnam	Typhoon Durian (Reming) The typhoon sweeps over the eastern province of Albay with wind speeds of up to 150 km/h, bringing severe rainfall during the night. Dozens of settlements are buried by mudslides triggered on the nearby Mayon Volcano by more than 200 mm of heavy rain.

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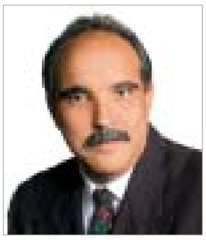

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