4. Earthquakes

The damage caused by earthquakes (Fig. 4) is the result of shifts in the Earth's surface and ground motions induced by seismic waves, as well as secondary phenomena triggered by the earthquake or the seismic waves (e.g., landslides, tsunamis).

Deformations occur because of extremely shallow and huge seismic events where the fault plane breaks through to the Earth's surface. The effects of these deformations usually are restricted to a relatively small area, but they may have far-reaching consequences if, for instance, structures with increased secondary risks, such as dams or nuclear or chemical facilities, are affected.

Strong earthquakes ($M_W > 6.5$) with a very shallow focus and predominantly vertical dislocation that take place in the ocean may release sea waves (tsunamis) with devastating effects. European examples of earthquakes connected with tsunamis are the Lisbon earthquake of 1755 or the Messina earthquake of 1908.

In most cases, earthquake disasters are the result of energy released in the form of seismic waves that affect large regions. Buildings exposed to strong ground motions may partially or totally collapse. Also, strong earthquakes may induce changes in the Earth's surface that can cause slope movements and changes in river beds, as well as collapse of the soil structure.

4.1 Seismic focal and propagation processes

Current models of seismic ground motion in connection with strong earthquakes proceed from the conception of the interaction of complex focal processes and just as complex filter processes during propagation. The latter change both the amplitude and frequency of the seismic signals. Especially significant are surface-near interference processes that may lead, at certain frequency ranges, to strong amplitude magnification or damping, respectively, and to an altered duration of strong ground motion.

The assessment of expected seismic ground motion for a particular location relies on numerical simulation techniques that enable various interacting focal and wave propagation processes to be modeled in different ways. Such techniques are based on the study of the general regional seismotectonic situation. Different patterns of dislocation along a single fault result in considerable tectonic space problems. Therefore, a tectonophysical model is needed to interpret differences of motion reported by geomorphological, geodetic, paleoseismological, and recent seismological observations. The modeling of propagation effects can be done in different ways. First, it is possible to use general geological information, such as geological maps. The geological indications, whenever possible, should be supported by available seismological information. The numerical calculation is based on the assumption of plane or cyclic wave fronts that extend in a medium with horizontal stratification. The attenuation features of the propagation medium are described by means of visco-elastic laws.

Research requirements:

- causes of the frequently observed focal and propagation effect (f_{max}-effect. f_{max} is the maximum cut-off frequency of a seismic spectrum, whether this cut-off frequency is determined by the focal process, the propagation medium, or different effects of both is unsettled);
- dominating absorption mechanisms.
- modeling of the influence of surface-near layers and structures; and
- applicability of linear stress and strain relations to the field of engineering seismology and, closely connected to this, the transferability of results of the investigation on microearthquakes.

Problems/tasks:

- possible misjudgment due to unjustified assumption of horizontal stratification;
- determination of source parameters (e.g., focal magnitude, focal mechanism, focal depth, inner structure of the dislocation process);
- occurrence of very shallow earthquakes with dislocations in the Earth s surface; and
- development and propagation of tsunamis.

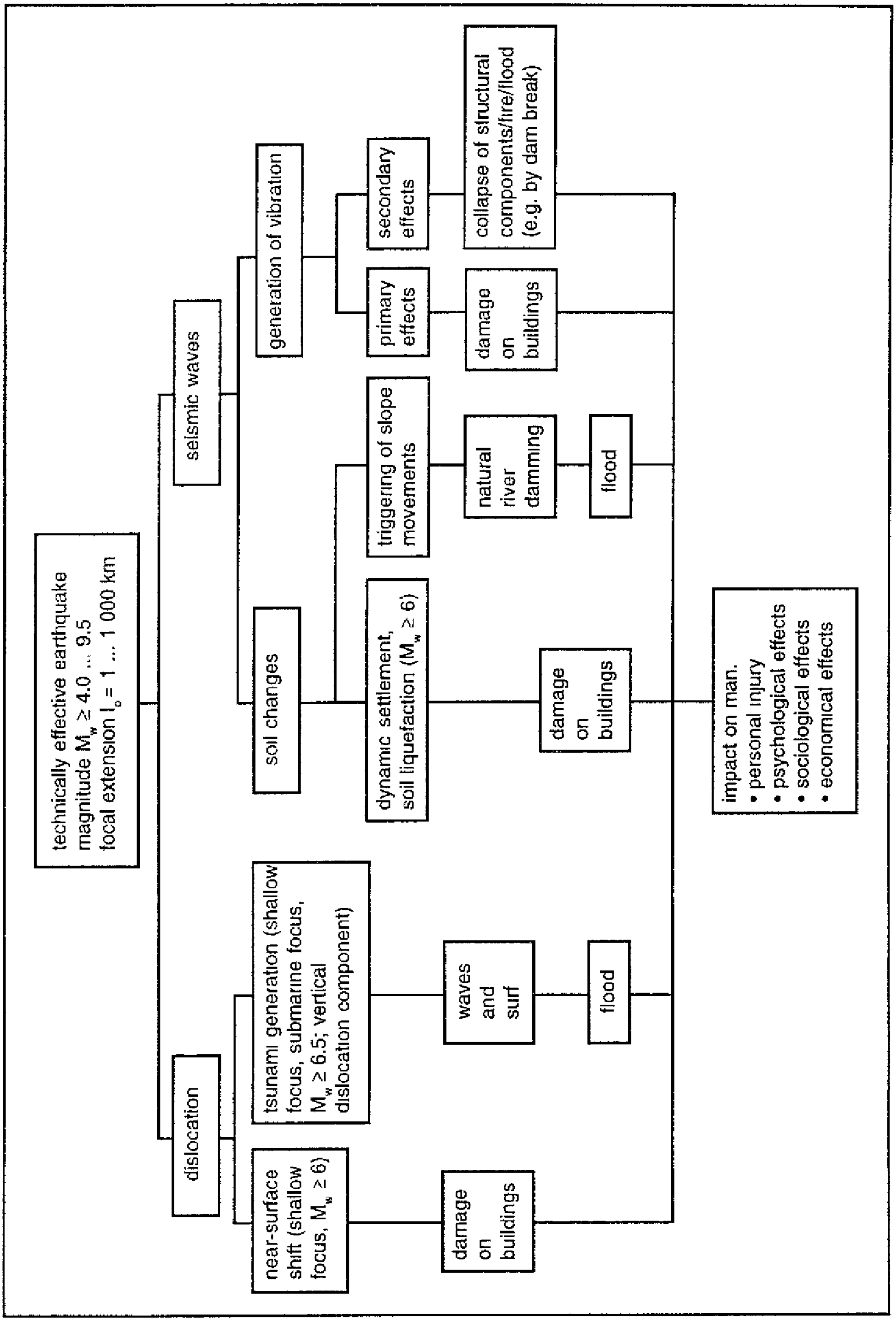
4.2 Aftershocks

Practically all stronger earthquakes are followed by aftershocks whose number and strength diminishes with time. Aftershocks generally can be seen as a continuation of the fracture process of the principal earthquake and are expressions of stress shifting and heterogeneities of stress and shear strength within the focus Therefore, aftershocks are an extremely important source of information needed to determine the location and orientation of the main shock focus or the laws of amplitude attenuation. However, information gathered from aftershock activity is of value only if these activities are recorded as completely as possible, which requires installation of mobile seismic nets immediately after a stronger event.

4.3 Seismic hazard analysis

Preparedness measures aimed at reducing and avoiding earthquake disasters and earthquake management planning are based on detailed knowledge about the regional and temporal distribution of earthquake hazard. Within the seismic hazard analysis. the occurrence of earthquakes is viewed as a stochastic event. Hitherto, earthquake activity frequently has been reduced to a Poisson-process that does not quite apply to reality. The purpose of analysis is to obtain a time-independent, regionally specific, magnitude entry rate for future earthquakes. By relating the entry rate to a normative area. the entry rate can be regarded as a main seismicity parameter for location analysis, which allows the computation of entry rates of macroseismic intensity for any location within a model region. Based on these rates, probabilistic earthquake hazard maps can be prepared that show the spatial distribution of earthquake intensity with distinct occurrence probabilities.

Figure 4: *Damage causing effects of earthquakes (after Schneider)*


technically effective earthquake
magnitude $M_w \geq 4.0 \dots 9.5$
focal extension $I_o = 1 \dots 1\,000$ km
dislocation
seismic waves
near-surface shift (shallow focus, $M_w \geq 6$)
tsunami generation (shallow focus, submarine focus, $M_w \geq 6.5$; vertical dislocation component)
soil changes
generation of vibration
damage on buildings
waves and surf
flood
dynamic settlement, soil liquefaction ($M_w \geq 6$)
triggering of slope movements
natural river damming
flood
damage on buildings
primary effects
secondary effects
damage on buildings
collapse of structural components/fire/flood (e.g. by dam break)
impact on man:
• personal injury
• psychological effects
• sociological effects
• economical effects

Research requirements:

- knowledge of the correlation between magnitude (focal energy), focal depth, and macroseismic intensity in the epicenter for different focal areas;
- factors that influence the attenuation of intensity in connection with increasing epicentral distance;
- effects of possible secular changes of seismicity in certain focal areas on the deviation of the temporal occurrence of events from the Poisson-model;
- regionalization of focal areas of earthquakes by means of geological, tectonic, and microearthquake investigations;
- refinement of the seismicity model used for analysis;
- influence of the local geological soil and underground conditions on the propagation of seismic waves, and thereby on macroseismic intensity; and
- local occurrence rates of epicentral intensity supplemental to statistical evaluations (probabilistic for small occurrence rates).

4.4 Soil-structure interaction

Numerous earthquakes have demonstrated that dynamic interaction, especially at resonance, causes high levels of damage. Therefore, research of all interactive processes connected with earthquakes, as well as the early transfer of new findings into applicable codes and standards, is of great importance. Problem areas are soil-structure and soil-structure-fluid interactions.

The determination of the behavior of the entire structure-environment system during an earthquake is possible only through the correlation of experimental data with sufficiently exact, high-performance, numerical methods.

Numerical methods include quasi-static and dynamic numerical procedures (finite element, finite difference, and boundary methods), as well as numerical hybrid area-boundary methods and probabilistic/stochastic methods. Until now, analytical and numerical investigations in the field of soil-structure and soil-structure-fluid interaction predominantly were carried out through the use of linear models, whereas foundation and structure were considered a rigid body. The behavior of different building foundations in response to arriving seismic waves has been studied sufficiently as long as an elastic or visco-elastic behavior between foundation and soil was assumed. However, little investigation with realistic ground models exists for fully three-dimensional structures in near-to-reality dynamic interaction. For soil-structure-fluid interactions, nonlinear effects were seldom taken into consideration numerically. However, instructive studies were done for various components, such as storage tanks and dams.

Experimental methods include prototype or scale-model tests. Measurements in both cases are accelerations, velocities, or displacements. Some experimental studies of soil-structure interaction do exist, but no investigations on soil-structure-fluid interaction are known.

Research requirements:

Analytical-numerical investigations:
- soil damping of ground material;
- dynamic soil interaction between several structures,
- ground as a multiphase system,

- recording of nonlinearities in contact zones; and
- detailed parameter studies.

Experimental investigations.
- recording of soil damping characteristics;
- ground-wave propagation and its interaction with structures;
- investigation within the frequency range with respect to the fundamental period of structures; and
- ground as a stratified half-space.

Comparison of experiments and numerical models:
- development of reference parameters.

4.5 Concrete and masonry buildings

The main task of earthquake protection is the planning, design, and detailing of structures to channel and distribute earthquake energy and to enable its transformation into other forms of energy to avoid damage. During strong events, the relatively low energy dissipation by damping is often not sufficient to reduce the transmitted energy quickly enough. Therefore, it is important to activate cyclically—as another form of vibration energy transformation—ductile deformations that then become the main part of the energy dissipation.

The behavior of *building materials* under a dynamic impact that causes high load intensities essentially is determined by such things as strain velocity, nonlinear deformations, and the number of load cycles. Generally, the nonlinear behavior under cyclic load is the decisive factor. Although concrete and masonry exhibit a relatively low capacity of nonlinear behavior, such a response may be enhanced by an appropriate layout of reinforcing steel. For this, a rather large ratio between tensile and yield strength is essential, the use of cold-formed steel is less desirable.

The behavior of *structural components* depends on the design and geometrical characteristics as well as on the behavior of the building material. Flexible components with high bending strength are more favorable than compact components. High compressive axial forces result in a significant reduction in ductility and may have an adverse influence on the behavior of structural components.

The *overall* behavior of buildings during earthquakes is affected by the behavior of the individual structural components and their connections as well as by their combination and interaction. A favorable building behavior requires a deliberate channeling of the dissipative processes, (i e , a useful distribution of strain capacity and viscosity over certain parts of the building). Hence, the overall and detailed layout of the structural design is of vital importance for an earthquake-resistant design. If such principles are not incorporated, stress concentrations in parts of the building may lead to serious damage.

Because of the energy dissipation under cyclic deformation in the nonlinear range, a crucial problem in the building design is an accurate assessment of the attenuation of earthquake-induced stresses in the elastic system. Reflecting this potential nonlinear behavior, more recent building codes specify so-called behavior factors that effectively permit reduction of earthquake design values in the elastic system. However, the behavior factors given in the codes are based on estimates that reflect the presumed interactions between behavior factors and construction details

Research requirements:

Building material:

- confinement effect of various stirrups and their influence on the behavior of concrete under cyclic strain; and
- development of energy dissipation for masonry walls under nonlinear deformations.

Structural components:

- behavior of structural components under predominant shear loads;
- behavior of short structural components (under both high shear and high axial loads) under cyclic loading in the nonlinear region;
- measures to prevent explosive shear fractures; and
- ductile rotation capacity in critical parts of concrete components reinforced with high-strength, low-ductile steel.

Buildings:

- interaction of frame and masonry in fill walls in skeleton structures.

General.

- rules for assessing the influence of code-deviating design principles for buildings on the distribution of energy dissipation due to nonlinear behavior.

4.6 Steel structures

Based on world-wide experience and the excellent performance of steel structures during exposure to earthquakes, present-day codes and computer-assisted design and calculation methods for steel structures permit the design of different steel earthquake-resistant construction systems The ductile, energy-absorbing systems are typically either *steel moment-resistant frames* or *steel eccentrically* or *concentrically braced frames* The last system may be used only as a ductile system under certain special conditions in layout and design details. In general, the first two systems are preferred.

Although less commonly used, composite construction, which uses steel sections with reinforced concrete as an infill for both beam and column members, offers an excellent alternative to the common bare-steel framed systems typically used in earthquake-resistant design. Specifically, the nonlinear ductile behavior of both welded and high-strength bolted beam-column connections of composite moment-resistant frames, as well as the ductile, nonlinear response of composite beam shear-links in eccentrically braced frames, guarantee a fully reliable, cyclic, energy-absorbing performance of such systems under earthquake conditions.

Also, the use of steel or composite steel-concrete elements together with concrete elements, which form a hybrid system, offers excellent possibilities to ensure the ductile, energy absorbing, nonlinear behavior of various building systems. Recent studies indicate that, particularly for developing countries where post-earthquake damages often reach catastrophic proportions, a hybrid system with composite column sections (i.e., steel tubular sections filled with concrete) and a typically reinforced concrete beam and floor-slab system, are high-performing structural solutions capable of withstanding extreme earthquake exposure. This system is particularly attractive when it utilizes the expertise of the local industry in both concrete design and construction (for the floor-slab system) and introduces a new technology (composite columns) only to a limited extent. Another hybrid system that uses composite steel-concrete beam shear-links as coupling elements between reinforced concrete shear walls offers similarly good ductile, nonlinear characteristics for an effective earthquake-resistant design.

Research requirements:

- further studies on the use of hybrid systems suitable especially for developing countries

4.7 Components and installations

Components are technical installations supported by the structure and located either inside or outside the structure. These components include house-installations, as well as processing and electro-technical equipment In a wider sense, they also include certain technical installations placed directly on or in the ground or installations whose layout dominates the supporting structure. Secondary structural elements that do not belong to the resisting structural system, such as partition walls, chimneys, cladding, and balconies, fall under this general category.

The design concept of components is based on defining the structural resistance, overall integrity, and functionality of the structure. Until now, the design of components and installations to reduce their vulnerability is not or is insufficiently defined in national building codes. Only the layout and design of components and installations for nuclear facilities are thoroughly regulated and can be regarded nationally, as well as internationally, to reflect state-of-the-art. However, experience with earthquake damage indicates that calculations frequently overestimate the earthquake damage potential. General rules and codes for the layout of non-nuclear installations are not yet available.

Research requirements:

- definition of protection requirements within the frame of a disaster management concept enabling a risk-oriented classification of components and installations and an assigned degree of earthquake resistance;
- definition of design steps and accompanying requirements for an assessment of the structural integrity with emphasis on simplified procedures;
- definition of construction rules based on a broad experience, with the possibility to replace common numerical procedures; such rules should be based on a systematic analysis of damage reports and test results;
- regulation of a graduated load limitation in consideration of the load transfer through the building, building-component interaction, and interaction between individual components; and
- compilation of assessment criteria and, if applicable, instructions for procedures to strengthen existing components and installations not designed to withstand earthquakes.

4.8 Isolating mechanisms

Earthquake-resistant structures may be divided into two categories: *highly resistant structures* and *vibration-controlled structures*. Seismic isolation offers a passive vibration control by uncoupling the building, placed on springs and damping elements, from the seismic ground movements and effectively reduces the dynamic input to the building. The topic has been the subject of extensive theoretical studies. Experimental studies using large-size shaking tables have been limited. Only in a few cases have response measurements been recorded during seismic events.

Contrary to passive vibration-control measures, active control measures (in connection with measured and counteracting devices) are presently realized only to a limited extent. The following aspects that affect the earthquake-resistant design of a structure are important:

- lightweight construction,
- high strength material;
- high ductility;
- shift in the natural frequency of the building; and
- increase of the structural damping.

Until now, although various ground motion data are considered, relatively simple mathematical models are used to calculate the earthquake response of structures. However, the actual earthquake engineering design process is given less attention.

Research requirements:

Analytical studies.

- three-dimensional, nonlinear structure/isolator models under large deformation;
- effects of long-term periods;
- nonlinearities in elastomeric and slide bearing elements;
- influence of parameter variability;
- different support settlements;
- interaction of horizontal and vertical as well as torsional and tilting movements; and
- preliminary design concepts.

Experimental investigations:

- use of large shaking tables or pseudo-dynamic test systems for the verification of new isolation concepts;
- experimental modal analyses of real structures;
- tests on stability and tilt resistance, and
- quality control tests for different base isolators.

Baseisolation and supplementary control measures:

- development and verification of supplementary control measures (e.g., elastically suspended structural parts);
- extension to semi-active and fully active methods;
- use of nonlinearities for vibration control; and
- three-dimensional supplementary systems.

4.9 Low-cost housing

In developing countries, about 50 % of the population lives under inadequate housing conditions. So far, government programs have been unable to solve this problem. Achieving maximum quality and security in housing for the poorest at minimum costs must be the primary aim of all efforts. The following factors are important for the development of earthquake-resistant houses:

- use of locally available building materials;
- do-it-yourself construction using simple techniques;

- maximum housing quality and durability at lowest possible cost;
- good insulation, noise absorption, and humidity regulation; and
- minimal ecological impact.

Because of the broad use of clay as a building material worldwide, the development of earthquake-resistant, low-cost housing for developing countries has concentrated mainly on clay construction. Within the framework of the IDNDR, a first step could be the development of earthquake-resistant housing construction in cooperation with one or more developing countries. Such an approach could lead to the development of a prototype house that would allow even the poorest population groups to obtain housing that is better suited to withstand future earthquake exposure. The German Association for Earthquake Engineering and Structural Dynamics (DGEB) has adopted this goal and has started work on a project entitled "Design of an earthquake-resistant adobe house".

Research requirements:

- earthquake resistance of local construction techniques.
- behavior of a prototype house under seismic loads;
- behavior of two-story clay structures under earthquake loads and improvement of their earthquake resistance;
- public education and information on the construction techniques needed to prevent earthquake damage of houses;
- integrated planning and layout of single housing settlements (land acquisition, development, infrastructure, disassembly, recultivation).

4.10 Strengthening of buildings

The strengthening of buildings in earthquake-prone regions is aimed at improving the resistance of buildings to seismic loads. This means to adequately increase the energy absorbing capacity of the load-bearing system by increasing the maximum horizontal load resistance and the ductility (i.e., the toughness of the structure) Materials used to retrofit buildings are conventional cast-in-place reinforced concrete, shrinkage-compensating concrete, polymer modified concrete, resin concrete, shotcrete, resins, and grouts.

For *steel structures*, increasing the load capacity in most cases is an easy process that involves the welding or bolting of additional steel parts onto the original construction.

The retrofitting of *reinforced concrete structures* is usually done by means of cast-in-place concrete where a durable bond between the old and new concrete is essential. Increasing the confinement of the concrete by closely spaced stirrups in order to increase the ductility of the strengthened components is most important.

Linear elements such as columns, beams, and girders can be strengthened by covering these elements with steel sections or plates bolted to the concrete members However, it is difficult to carry the strengthening across beam-column joint regions. Another possibility is gluing steel plates to the concrete sections with synthetic resin. This technique is easily applicable and does not result in an enlargement of the cross-section of the strengthened elements.

Masonry structures of stone or bricks are strengthened in the same manner as reinforced concrete buildings. The load-bearing elements of these structures are usually walls. Damage may occur because of bad workmanship or poor coupling between external and internal walls. An efficient way to improve the load resistance and toughness of masonry walls is the introduction of horizontal and vertical reinforced concrete elements. This is particularly appropriate for floor levels where a ring beam can be placed. Moreover, by placing steel sections against the wall surface, the load capacity and ductility may be increased particularly under loads acting normal to the wall. Also, strengthening walls with shotcrete results in a better load capacity, stiffness, and ductility. If and to what extent masonry can be reinforced by cement or resin injections depends mainly on the number of cavities and the extent to which these can be filled. Injection measures, however, should be combined with other measures of masonry strengthening.

Especially important is the stiffening of buildings by horizontal floor slabs. These slabs, acting normally as rigid diaphragms, distribute the inertia forces over various load-bearing walls, which act effectively as shear walls

Research requirements:

- research results exist primarily for single construction elements; no investigations have been done on connection regions and penetrations as well as on the interaction of various elements as they may affect the whole building or a significant part of the structure;
- the composite behavior of new and old concrete and its dependence on, for instance, the concrete quality;
- evaluating the quality of those possible solutions in which the forces are not or only partially transmitted by composite action, and
- reconstruction of architecturally valuable buildings (prefabricated parts and traditional architecture).

4.11 Regulations and codes

Regulations and codes for earthquake-resistant design include instructions and recommendations for all relevant data, ranging from earthquake input (spectrum) to design of single structural and nonstructural elements. These regulations and codes should reflect the state-of-the-art and are updated continuously. Today, because of a better assessment of earthquake intensities and more exact calculation and construction methods, it is possible to design earthquake-resistant structures. Presently (1993), 36 countries have adopted earthquake codes for conventional buildings and enforce these codes with varying efficiency, as the codes differ considerably from one country to the next. In some countries, additional codes exist for special buildings such as nuclear power plants. In Europe, an extensive collection of regulations that cover the earthquake-resistant design of buildings, bridges, tanks, pipelines, transmission towers, etc., is being formulated for obligatory adoption by all European countries. Existing regulations cover:

- restriction of the code validity for certain kinds of buildings;
- definition of earthquake zones;
- construction design requirements for buildings;
- determination of earthquake load;
- consideration of building torsion;

- load combinations covering dead weight, live loads, snow, and earthquakes; and
- design rules and regression coefficients for customary construction materials.

The determination of earthquake load is essential. For buildings, static equivalent forces are determined at points of mass concentration (usually at floor levels). Equally important is the structural layout and design of the building and its structural parts.

Special buildings (i.e., all buildings other than conventional buildings, e.g., power plants) differ from conventional buildings because of different construction as well as a higher secondary risk in case of earthquake damage (i.e , environmental impact, radiation) In certain regulations, rules for special buildings are included. In the absence of special codes, the designing engineer is responsible for the earthquake-resistant design.

For nuclear power plants and nuclear waste-processing facilities, extensive investigations and risk analyses of earthquake ground motion at the site and the earthquake design of such structures and facilities have been done and are reflected in the pertinent regulations.

Research requirements·

- compilation of standardized earthquake maps showing earthquake magnitude, intensity, and, if possible, response spectra in correlation with the return period;
- expansion of existing regulations for normal buildings for use in the design of special buildings;
- determination of specific applications of ductile structures;
- determination of efficiency of building inspection (rules and implementation),
- development of guidelines for typical houses, reflecting local characteristics;
- recommendations for a warning system and for behavior of the population during and after earthquakes;
- development of rules for building strengthening;
- development of rules for repair of earthquake-damaged buildings.
- development of rules for land-use restrictions in especially exposed areas; and
- development of guidelines for damage regulation and registration.

4.12 Basic research on earthquakes

For most earthquake disasters, regional conditions have a significant influence on the degree of disaster. Therefore, only careful local investigations can reveal the causes that led to disaster. For instance, a study of the 1985 earthquake disaster in Mexico City indicated that unexpectedly strong ground motions were the cause of the high degree of damage.

The causes of earthquake disasters often are not known in detail because of missing or insufficient investigations. In addition, repair and reconstruction frequently are carried out without or with insufficient know-how of regional planning or earthquake-resistant construction of rural, non-engineered structures.

In the 60's and 70's, the UNESCO commissioned the first investigations of earthquake disasters to be carried out by international teams of experts. Today, American scientists from the National Academy of Sciences, the Earthquake Engineering Research Institute (EERI), and other, sometimes private, institutions undertake damage investigations all over the world. Other countries regularly send teams of experts to seismic hazard regions as well (e.g., Japan, France, the United Kingdom, Italy, Australia). In Germany the Munich Reinsurance Company is doing research with the emphasis on economic and insurance aspects of natural disasters. At the Disaster Research Center of Kiel University, the response of Turkish people to earthquake warnings in the region of the Anatolian fault was empirically studied. At the Geographical Institute of the Technical University of Munich, reconstructions in Friaul (northern Italy) after the earthquake disaster of 1976 were analyzed for 12 years. Experts of the German Association for Earthquake Engineering and Structural Dynamics (DGEB) are engaged in solving the problems in the design and construction of earthquake-resistant buildings and structures in Germany and abroad.

Research requirements:

- as precondition for effective measures: worldwide systematic investigation of earthquake disasters on a broad interdisciplinary basis including aftershock records by mobile seismic stations.

4.13 Pre- and post-disaster measures

Experience with preparedness programs has increased, especially in Japan and California. Institutions established for this purpose serve as education and information centers, they organize preparedness measures, and they promote public awareness. Educational programs are successful in raising the awareness level among the population. By intensifying know-how transfer and information exchange between scientists, politicians, and media, pre-disaster measures can be organized more effectively. At the same time, insurance companies may influence preventive behavior of the public in a positive way by shaping premiums and conditions (own participation, damage limit) accordingly. Land-use regulations as another means of preparedness are not yet commonly applied.

Reconstruction measures, following instantaneous relief actions, must be the primary aim of post-disaster measures. They include:

- quick rejoining of families;
- establishment of shelters, if possible near the former place of residence; and
- quick allocation of work and income to the people affected.

The passing of reconstruction programs should be preceded by defining a settlement model. As a minimum, far-sighted planning should include the execution of seismic microzonations and the provision of construction rules. Demographic and social developments must be considered as well. Reconstruction planning must not be regarded merely as a response to the emergency situation.

Research requirements:

- investigation of the socio-economic effects of earthquake forecast;
- thorough elaboration of the local utilization of instructions for seismic zoning,

- long-term analysis of reconstruction projects together with their accompanying social phenomena;
- elaboration of concepts for long-term supervision and counseling for reconstruction projects after earthquakes, and
- influence of insurance conditions on preventive behavior and damage repair.

4.14 Seminars and courses for training and education

Broadly effective information, motivation, and, if needed, training and education for all target groups in society are basic requirements for meeting the aims of the IDNDR. Information and training deficiencies exist, especially in developing countries.

The analysis of offers of training from all over the world indicates that courses and seminars dealing with earthquake engineering and engineering seismology are numerous. The UNESCO training course "Seismology and Seismic Hazard Assessment" held by the GeoForschungsZentrum Potsdam on an annual basis, alternating between Potsdam and developing countries, is presently the only regular, worldwide open, crash course on seismological fundamentals and practice. Within the framework of the IDNDR and with the support of UNESCO and other national and international aid organizations, these training activities should be continued and complemented by an appropriate earthquake engineering component. In these courses, all participants are supplied with extensive lecture notes, recommendations for textbooks, and software, which provide maximum support to the future applied and research studies in their disaster-stricken home countries and regions.

4.15 Regional planning after earthquake disasters

Every reconstruction after a disaster is considered to be a state activity in terms of local development policy. Decision makers must be aware of the possible consequences of different structural designs in order to avoid the undesired side effects of reconstruction. In each potential earthquake area, concepts and plans should be prepared that enable and secure a revised regional and settlement structure. Such considerations also apply to regions threatened by other hazards. Well-proven concepts, such as development axes, disperse concentration, and point-axial settlement structures, should guide all rehabilitation initiatives from the beginning. Accommodation in barracks is an appropriate possibility for the phase between the provisional restoration of living conditions and moving into new houses. The barrack town may be used as an instrument to stimulate concentration of the population in central places or settlement centers, but the possibility of misuse for ends other than disaster protection should be kept in view. In addition, there should be a plan for emptying the barracks in order to avoid their persistent usage (e.g., by timing state subsidies for the construction of private homes).

The plan for reconstruction should not be merely a response to the emergency situation, but should coincide with desirable social development and be used to direct it. In terms of architecture, planning must consider social change. Earthquake disasters and the subsequent reconstruction drastically interfere with the social situation of a region. The all too technical, all too rational implementation of plans exposes the inhabitants to the danger of losing their already affected identity.

Research requirements.

- planning instruments for disaster management (e.g., planning sovereignty);
- mechanisms of planning instruments and their functioning in case of application; and
- objectives of planning instruments (e.g., for optimized settlements).

5. Volcanoes

About 50 to 60 volcanoes erupt every year worldwide. Large eruptions endanger life and settlement areas of millions of people living on the slopes or on the foreland of active volcanoes. Volcanoes with a high hazard potential are located mainly in third world countries (Latin America, Southwest Pacific) In these countries, eruptions are becoming increasingly risky because of rising population density and intense infrastructural interweaving in the areas surrounding volcanoes. However, compared to other natural disasters, such as earthquakes. the destructive potential of volcanic eruptions is lower, as eruptions are often predictable. Thus mitigation of volcanic hazards is feasible, reducing damage considerably provided that hazard and risk potential have been assessed correctly. To do so, detailed knowledge is needed about the structure and history of the respective volcano, eruption mechanisms, etc Apart from the numerous destructive effects of volcanic activity, the positive effects, such as fertile soil, geothermal energy, or the picturesque scenery, should not be forgotten.

5.1 Location, morphology, and products of volcanoes

Many volcanoes are located at the edges of lithospheric plates. Along the mid-ocean ridges (spreading zones), the plates are moving apart and new crust is being formed. Along subduction zones, plates collide and one plate is subducted beneath the other Intraplate volcanoes are located in the interior of oceanic or continental plates.

Volcanoes range from small scoria cones to large strato- and shield volcanoes. The morphology of a volcano depends on the eruptive processes which are largely governed by the chemical composition and volatile content of a magma. For instance, the higher the percentage of silica (SiO_2) in a magma, the higher its viscosity and the more explosive the eruptions. Highly liquid, basaltic lava builds shallow, broad shield volcanoes, whereas stratocones are formed by explosive and effusive activity of more viscous magmas.

Hazard assessment of volcanoes must consider the morphology and environment. The products of volcanic eruptions include lava, fragments (tephra), and intrusions. Tephra is classified according to the grain size of fragments into ash (< 2 mm), lapilli (2-64 mm), and bombs or blocks (> 64 mm). Attempts have been made to classify the intensity of a volcanic eruption, i.e., its volume and explosive power. Recently, the *volcanic explosivity index* has been used. The index is calculated from the volume of erupted material and the height of the eruption plume. Additionally, qualitative descriptions of an eruption are used to determine the index.

5.2 Types of dangerous volcanic activity

The longer a volcano has been inactive, the greater, usually, the volume of the ejected masses and the more explosive the eruption. Long periods of dormancy between eruptions are characteristic for many volcanoes The question of when to call a volcano extinct is not easy to answer; some volcanoes become active again after thousands or hundreds of thousands of years.

High-risk volcanoes are volcanoes that (1) erupt one or more times during one decade, (2) are poorly investigated or monitored, and (3) have dense populations inhabiting the area. Following the emptying of a large magma reservoir, the top volcanic structure collapses, and a caldera is formed.

If magma encounters groundwater during its ascent toward the Earth's surface, an explosion-like vaporization of the *water* occurs (phreatic explosion when only wall rock is fragmented; phreato-magmatic when new magma is involved). Such eruptions are often accompanied by base surges, currents of immense destructive power which consist of gases and fragmented rock flowing horizontally and radially away from the eruption center.

Lava flows are less dangerous to human life than to property, traffic, and communication lines Because probable paths of lava flows can be roughly predicted, diversion measures may be taken in principle, however, such measures often turn out to not be very successful. Highly viscous lava generally does not advance far, but commonly piles up above an active vent as a lava dome. Such domes can collapse repeatedly and generate dangerous hot block and ash flows and hot surges and blasts.

Poisonous, even lethal, *gases* can be ejected during the eruption of a volcano or can be released without a triggering eruption. The time available for early warning of gas release is extremely short, and intensified investigations on such gas eruptions, as well as keen observation of the respective locations, are absolutely necessary.

Ashfalls during volcanic eruptions generally do not directly endanger life, although the collapse of roofs and houses under the ash load are not uncommon. Considerable damage may be caused, however, for agriculture and industry even at distances up to tens of kilometers from a vent

Pyroclastic flows and low-density *surges* that are frequently associated with blasts are extremely hazardous types of volcanic eruptions. Pyroclastic flows consist of a mixture of volcanic gases and ash and are generated during many volcanic eruptions. Some may be as hot as 800° C; they move swiftly with velocities of up to several 100 m/s. Early warning for this volcanic phenomenon is virtually impossible. A most dangerous situation develops if pyroclastic flows are generated on snow- or glacier-covered volcanoes, causing the cover to melt.

Lahars (volcanic mud and debris flows) are a common major volcanic hazard for people and property. Lahars likewise proceed very quickly and possess great destructive power. They develop either as a direct consequence of a volcanic eruption, if, for instance, crater lakes are blown out, or as a secondary event as a result of heavy rainfall during or after the eruption. Areas farther away may be warned several hours in advance. A sufficient monitoring of individual volcanoes, however, rarely is guaranteed.

Volcanic *debris avalanches* generated by sliding of larger portions of volcanic cones are common. These avalanches are highly mobile and may not only bury large tracts of land but also cause devastating tidal waves (tsunamis) if they advance into lakes or the sea.

Damage and hazard to human life, social structure, and property may not be induced only by direct effects of volcanic eruptions. Some of the most dangerous *secondary phenomena* are tsunamis, contaminated (e.g., fluorine-rich) ashes, or long-lasting aerosol clouds that can orbit the Earth for years after large volcanic eruptions. Aerosol clouds basically consist of condensed volcanic gases, mainly sulfuric acid. The emission of large quantities of SO_2 and also possibly halogens into the stratosphere may lead to a temperature decrease on the Earth's surface by increasing the global albedo and also can contribute significantly to the destruction of the stratospheric ozone layer.

The correlation between volcanic hazards, destructive potential, and the erupted mass is not universal. In many cases, the destructive potential depends less on the mass and temperature of the erupted material than it does on the specific environment of the eruptive center, especially the degree of magma-water interaction and the energy of the initial blasts.

5.3 Prediction of volcanic eruptions

The development of methods to predict volcanic eruptions is extremely important to provide for early evacuation of densely populated regions. Hazard and risk potential of volcanoes can be localized reasonably well, unlike some other types of natural disasters (earthquakes, storms). Reliable predictions, to a minimum degree, however, are only possible for volcanoes that are well studied and sufficiently instrumented. A prediction based on the statistics of previous eruptions is too vague for specific and short-term prediction of an eruption. A *forecast* is a general announcement that a volcano will probably erupt in the near future (e.g., by qualitative signs of unrest). A *prediction* is a relatively precise statement that describes the part of a volcano that is likely to erupt, the time of the eruption, and the presumable type of eruption. Such predictions must be made public with utmost caution in order to gain credibility within the concerned population, thus enabling adoption of preparedness measures. Our increasing understanding of processes inside volcanoes and their measurable effects put predictions more and more on a deterministic basis.

The careful analysis of the history of a volcano is the most important method in assessing the long-term probability of the occurrence of a specific eruption type and its eruptive energy. Volcanic eruptions are often announced years, months, days, or hours before (e.g., by harmonic tremors in the deeper conduit system). This microseismic activity commonly increases prior to an eruption and is characterized by relatively constant amplitudes and wave lengths that are possibly caused by the turbulent motion of the magma ascending to the surface from a magma chamber.

The relatively slow ascent of viscous magma to the upper crust generates a surface expansion that can be measured with modern geodetic instruments. Temperature increases within a volcano as a result of ascending magma can be detected by infrared signals via satellite. Heat conductivity and the magnetic field are changing. An increase of SO_2 emissions often has been observed before eruptions. The characteristic behavior of a volcano can be identified with the help of intensive monitoring by satellite.

5.4 Prevention and mitigation of volcanic hazards

To prevent future disasters, or at least to reduce their extent, a series of measures must be taken before, during, and after a volcanic eruption. Various regional research centers—especially in Latin America and South East Asia—should be established that have archives containing all relevant material and that can serve as centers for training of volcanologists, for public education, and for cooperation with other scientific institutions. The preparation of hazard maps helps to determine whether a volcano is potentially hazardous and to assess the risk. For that purpose, detailed knowledge about the history and characteristics of the specific volcano is indispensable, which requires, among other things, topographic and geologic mapping. Hazard maps show the pathways of eruption products to be expected (such as lava flows or pyroclastic flows) for various eruption intensities. Monitoring of volcanoes by satellites has to increase in order to detect possible changes (e.g., temperature or SO_2 emission). Continuous monitoring is essential When a volcano has been identified as potentially dangerous, ground monitoring (visual and instrumental) should be ensured.

The public must be informed and educated on the results of volcanological studies and any possible dangers. This can be done through the use of brochures, lectures, or courses. For potentially dangerous volcanic regions, emergency plans must be worked out, particularly evacuation plans for the population in case of immediate danger. Disaster prevention exercises, as already carried out in Japan, are useful as well.

A volcanic eruption can not practically be influenced by man. There are, however, limited possibilities to controlling several of its effects, such as barriers against lava flows or cooling lava with sea water. Smaller lahars can be channeled by artificial sabo dams. Another possibility to prevent the generation of lahars is artificial draining of crater lakes. Long-term regional planning can significantly reduce the hazard potential.

5.5 Recommendations of the International Association of Volcanology and Chemistry of the Earth's Interior (IAVCEI) for the IDNDR

It is proposed that 10 *decade volcanoes* be studied intensively to contribute to the mitigation of volcanic hazards. The investigation will be carried out in an integrated, multidisciplinary, and multinational approach, including local authorities and the public (Fig. 5). The study should be based on the presently available possibilities. We suggest that the volcanoes Irazú (Costa Rica) and Cotopaxi (Ecuador) be studied in detail. In Germany, the Laacher-See region is a suitable research area. Three projects should be realized for this region volcanological study of the eruptive products of the 13,000-year-old eruption, hazard and risk mapping, and monitoring of gas composition. Further studies include,

- mechanisms of water-magma interaction;
- generation and transport mechanisms of pyroclastic flows;
- fragmentation mechanisms of magma; and
- subaerial and submarine slamps and debris avalanches

The IDNDR will contribute to improved communication between the scientists of different countries (periodical meetings, establishment of an electronic communication network). In addition, volcanological training courses should be offered.

Intervention measures by international and national expert teams should be expanded. Current developments emerging from activities within the scope of the IDNDR should be published irregularly in international journals, news bulletins, or the IAVCEI News (*Bulletin of Volcanology*). Eventually, a series of monographs should report on major IDNDR projects, among them one volume on each decade volcano.

***Figure 5:** Investigation of high risk volcanoes and mitigation of volcanic hazards (after Tilling)*