7 EARTHQUAKES

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7.1 C IARCTERISTICS AND DAMAGES

An earthquake is a sudden ground motion produced by abrupt displacement of rock masses, usually within the upper 5 to 30 km of the earth's crust. Most earthquakes result form the movement of one rock mass over another in response to tectonic forces. The rupture of the rock masses causes the ground to vibrate at frequencies ranging from about 0.1 to 50 Hz (cycles per seconds). As a generalisation the *shaking* ***severity*** increases as the magnitudes **of** the earthquake increases, and decreases as the distance form a **site** to the fracture plane increases. Experience shows that surface geological materials and the topography may influence the level and nature of the ground shaking strongly, **an** effect often underestimated in current hazard assesssments.

> There are no means to prevent earthquakes and currently no possibility exists to predict short term occurence with accuracy in terms **of** location and size of earthquake and time of occurence. The only possibilities to reduce the earthquake damages are appropriate planning and construction measures.

In terms of human and economic loss seismic shaking is the most significant factor contributing to the overall earthquake hazard. Shaking conmbutes to losses not only through ***direct vibratory*** *damages* to man-made structures but also indirectly through triggering of *secondary effects* such as landslides or rockfalls or even other forms of ground failures (soil liquefaction, slumping or settleinents). Thus, an important element in seismic hazard zoning on a regional basis is the geographical assessment of potential ground shaking.

In addition to strong ground motion, a variety of associated phenomena can cause serious damage and loss of lives:

Surface faulting. The offset or tearing of the earth surface by differential movements across a fault is an obvious hazard to structures built across active faults. A variety of structures have been damaged by surface faulting, including buildings, railways, roads, tunnels, bridges, canals, water wells and water mains, electricity lines and sewers. Surface faulting can be particularly severe to structures partly embedded in the ground and for underground pipelines or tunnels. Surface faulting generally affects a long and narrow zone ranging from few meters to more than 100 m. Subsidiary branch faults have extended as much as 10 km from the main fault and secondary faulting has been observed more than 25 km away from the main fault. The lengths of the rupture have ranged from few 100 m up to about **400** km. Their size is important for zoning purposes around active faults.

Tectonic subsidence and uplift are usually accompanied by surface faulting. The deformation may be local, affecting a narrow zone near the fault break, or may involve major differential vertical and horizontal movements over broad parts of the earth crust. This local deformation can distort or tilt structures. Regional tectonic deformations constitute a hazard to shore-line facilities and extensive hydraulic systems where broad scale changes in land elevation occur relative to the water level. Such changes can affect hundreds of square km of the earth surface and can damage harbour facilities, canals and other structures. During the 1964 Alaska earthquake for example piers, docks, breakwater structures, roads, railways, airstrips, and buildings were tectonically lowered relatively to the sea level resulting in permanent or intermittent inundation. In oilier areas tectonic uplift caused shallowing of harbours and waterways and thus restricted their use.

Landslides, rockfalls, avalanches. Earthquake shaking can dislodge rock and debris on steep slopes, triggering rockfall, snow and ice avalanches. Ground shaking can initiate shallow debris slides on steep and less often rock slumps and rock fall on moderate slopes. Under certain geological conditions shaking can reactivate dormant slumps or block slides. Avalanches can be triggered in weakly cemented fine graded material, such as loess, that form steep stable slopes under ncn-seismic conditions. Even small water-saturated sand lenses can mgger major landslides in nearly horizontal clay deposits, as occured in the 1964 Alaska earthquake in Anchorage.

Liquefaction. Areas having layers of water-saturated loose fine sand or silt typically deposited in the past 10'000 years can temporally loose their strength and behave as a viscous fluid due *to* severe ground shaking. Structures founded on such deposits settle, tilt or rip apart (Japan) as the soil spreads laterally. Buried structures may float up. Ground shaking can cause lateral movements on the top of liquefied surface layers. Such large ***subsoil*** *deformations* usually interrupt service lines (water supply, sewer, gas or electricity). Due to soil liquefaction the port facilities of Kobe for instance were out of service for several months **due** to the February 1995 earthquake. In the harbour area the entire watersystem went out of service due to liquefaction, induced excessive subsoil deformations, and hindering also fire fighting activities.

Tsunamis. **A** tsunami (Japanese word meaning harbour wave) consists of a series of long waves caused by a sudden vertical displacement of a large area of the sea floor during **an** undersea earthquake. In deep water the waves may not be observed. Upon reaching shallow water around islands or the continental shelf the height of the wave increases greatly reaching 30 m and a speed of over *SO* **km** per hour. The devastating wave front of a tsunami crashes inland, sweeping all away sometimes beaching ships hundreds of meters inland. Successive wave crests, typically arriving 10 to 45 minutes later, may continue to pond the coast for several hours. Several days may pass before the sea returns to normal state.

Seiches. In lakes tectonic movements can induce long waves also, with a period of several minutes to few ten minutes. These can spill low level shores or dams causing erosion damage.

7.2 IMPORTANCE OF INFRASTRUCTURE FOR DISASTER RESPONSE AND REHABILITATION

As already mentioned, earthquakes cannot be prevented and there are no possibilities to predict short-term occurence with any degree of accuracy. Earthquakes affect large areas by various effects and may produce enormous hiitriati and economic losses. They have therefore a significant effect on development of a country. *Earthquake* ***resilient*** *infrastructure* becomes a prerequisite for an effective disaster response and fast reconstruction activities after an event as for fast economical recovery.

In *developing countries* governmental organisations and industries are usually concentrated to few heavily populated areas. **An** event in such an area has **an** enormous effect on such a country. The development of the whole country can be *set* back for years leading also to further social and political problems. Disaster resilient, particularly earthquake resilient infrastructure is an important issue of the overall sustainable development process of such a country, therefore.

7.3 VULNERABILITY OF INFRASTRUCTURE

Vulnerability is defined as the degree of loss to a given element at risk resulting from a given hazard at a given severity level (e.g. vulnerability of a **4** stoned office building of masonry type in an earthquake intensity MSK XI). For an infrastructural system one has to distinguish between the system Vulnerability and the vulnerability of each component (service lines, structures, or control systems). Conventional vulnerability assessment concentrates often only on structural vulnerability (damage to the structural system), but the functional vulnerability is at least as important. *Functional vulnerability* usually is higher than structural vulnerability, such tliat functional failure precedes the structural failure. Functional vulnerability often can be reduced with highly cost effective means.

7.3.1 Characteristics of infrastructural systems

Every infrastructure-system consists of structures (individual and interconnected structures), equipment, power-supply, control systems, etc. One distinguishes between ***object-oriented*** systems (OS) as hospitals, police- and fire-stations, central food-storage **and** network-oriented systems (NS) as electricity-, gas-, water-, sewer-systems.

The following types of infrastructural systems are particular important **during** disasters:

Public Services:	Hospitals (OS) Police-stations (OS) Fire-stations (OS) Central food distribution centres (OS)
Water:	Water supply (NS) Sewers (NS)
Transportation:	Roads, highways (NS) Railways (NS) Airport (OS) Harbours (NS)
Telecommunication:	Surface based telecommunication (NS) Modular telecommunication (OS)
Energy supply:	Electricity (NS) Gas (NS) Petrol, Gasoline (OS or NS)

The characteristics and the individual importance of those systems and its components vary in every country from site to site.

7.3.2 Vulnerability of infrastructural systems

In a infrastructural system not every structure, or subsystem has the same importance to maintain the functionality of the system. During a disaster not every public service has to function to the same extent as in normal times, e.g. to maintain the public health system in emergency periods. Not every hospital has the same importance, and equal emergency capacities. The responsible *authorities* of every infrastructural system have do define services to be provided during each type of disaster. This so-called *reduced mode* will vary with the disaster type and its intensity. The system vulnerability has to be evaluated to maintain such reduced modes. To carefully define reduced modes of services is a delicate political problem with ecnomic consequences.

Line-based systems as water and power lines cross wide areas with different geological and topographical conditions involving local and temporal interruptions. Such systems can most effectively be strengthened by introducing some network redundancy. Redundancy also improves the *operational availabilities* in normal times.

The behaviour or object-based systems depends heavily on local site conditions. **A** careful *site selection* with respect to earthquake hazard is important. Avoiding unfavourable site conditions such as loose soil deposits, or high water table reduces the hazard damages. When strengthening is foreseen, the influence on the shaking level and the overall underground behaviour has to he evaluated carefully. Practical experience demonstrates often lacks in this regard.

7.3.3 Vulnerability of infrastructural components

Structures

Methods to asses the vulnerability of structures are well established. Experience from past earthquakes demonstrates that structures built according to modem codes, typically later than 1980, face limited damage. Methods also exists to assess the behaviour of underground due to strong shaking (e.g. liquefaction potential). At least some parts of an infrastructure have also to fulfill serviceability criteria.

Mechanical *and electrical components*

Experience for the assessment of vulnerability for ordinary mechanical and electrical equipment under earthquake excitation is not really available.

7.4 RISK MITIGATION MEASURES

Mitigation means taking actions to reduce the effects of a hazard before it occurs. The term mitigation applies to a wide range of activities aiming to better assess the hazard and to reduce the vulnerability of systems. These can range from the physical protection, like constructing stronger buildings and strengthening existing structures, introducing redundancy in a system to procedural *improvements* like introducing standard techniques for incorporating hazard assessment in land-use planning, or preparation of disaster response and reconstruction plans.

Building disaster-protection takes time. In urban areas most of the infrastructure is not built to modem codes and quality assurance methods. In rural areas most buildings and **part** of the infrastructure are non-engineered. To achieve an earthquake resilient infrastructural system, therefore, takes time and requires a continuous effort in improving the system resistance, maintaining or improving the system safety level and providing the necessary funding. This task is difficult for disasters with longer return periods like earthquakes. An entire earthquake resilient infrastructural system is economically nor feasible as also not reasonable. Therefore, a *priority* of real needs is based on:

(1) Careful definition of the required reduced mode of the system,
(2) Evaluation of the importance of all system components to maintain the reduced mode,
(3) Hazard assessment taking into account local conditions and
(4) Vulnerability of the important components.

Mitigration planing should aim to develop a *safety* culture in which all members of the society, from regional to local governmental orgariisations, leaders of industries and services as well the general public are aware of the hazard they face and will support mitigation efforts.

The main principles to achieve an earthquake resilient infrastructure system are:

- Design of *service networks systems* (transportation, water supply and sewer, energy supply or telecommunication) needs careful planning to reduce the systems *failure*. Long supply lines cut at any point. Interconnected networks are less vulnerable to local failures provided that individual sections can be isolated when necessary. Systems with centralised control facility again involve a higher **risk** than decentraiised systems with several interconnected control centres. In such systems redundancies are a must.

- Careful location of *new facilities*, in particular infrastructural systems as also community facilities like hospitals or schools play an important role in reducing settlement vulnerability in urban areas. Deconcentration of risk elements is important. Microzoning of earthquake hazard is a basic tool for risk mitigation.

- Link between different sectors of economy may be vulnerable to disruption by disaster. *Diversification of the economy* is a way to reduce the **risk** of economy breakdown in the aftermath of an event and thus reducing the capability of a fast recovery. **A** strong economy seems to be the best defence against any type of disaster. Within a strong economy, governments are able to maintain a resistant infrastructure and provide economic incentives to encourage institutions and individuals to take disaster mitigation measures.

The main steps of *earthquake risk mitigation* can be summarised as follows:

- Assess carefully regional and local settlements, economy and social vulnerability. **Assess** also the effects of large events on the economical and social conditions. Set priorities where and to which extent mitigation measures are mandatory.

- Define infrastructural systems important for disaster response and reconstruction.

- Define socially and economically acceptable functionality for every infrastructural system.

- Assess carefully hazard by taking into account regional and local geological and topographical effects as well as secondary hazards mggered by earthquakes.

- Assess infrastructural system vulnerability taking into account structural and functional aspects as well as redundancy and fast repair possibilities.