

Vulnerability of Infrastructure

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1. Characteristics and Damages

An earthquake is a sudden motion of the ground produced by abrupt displacement of rock masses, usually within the upper 5 to 30 km of the Earth's crust. Most earthquakes result from the movement of one rock mass past 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 from a site to 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 hazard assessments to day.

There are no means to prevent earthquakes and currently no possibility exists to predict short term occurrence with accuracy in terms of location and size of earthquake and time of occurrence. 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 contributes 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 settlements). 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 build 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 length of the ruptures 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 other areas tectonic uplift caused shallowing of harbours and waterways restricted their use.

Landslides, rockfall, 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 non-seismic conditions. Even small water-saturated sand lenses can trigger major landslides in nearly horizontal clay deposits, as occurred in the 1964 Alaska Earthquake in Anchorage.

Liquefaction. Areas having layers of water-saturated loose fine sands or silt typically deposited in the past 10'000 years can temporarily lose their strength and behave as a viscous fluid due to severe ground shaking. Structures founded on such deposits settle, tilt or rip apart as the soil spreads laterally. Buried structures will 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 30m and a speed of 50 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 pound 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.

2. Importance of infrastructure for disaster response and rehabilitation

As already mentioned, earthquakes can not be prevented and there are no possibilities to predict short-term occurrence with any degree of accuracy. Earthquakes affect large areas by various effects and may produce enormous human 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 recovery of the economy.

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

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 an 4 storied 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 if 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 that functional failure precedes the structural failure. Functional vulnerability often can be reduced with highly cost-effective means.

Characteristics of infrastructural systems

Every infrastructure-system consist 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 etc. 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) Airports (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 vary in every country from site to site.

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 has to 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 often with economic consequences.

Line-based systems as water and power lines crosses 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 of object-based systems depends heavily on the local site conditions. A careful *site selection* with respect to earthquake hazard is very 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 be evaluated carefully. Practical experience demonstrates often lacks in this regard.

Vulnerability of infrastructural components

Structures

Methods to assess the vulnerability of structures are well established. Experience from past earthquakes demonstrates that structures built according to modern codes, typically later than about 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 infrastructures have also to fulfil 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.



Figure 1: Damaged equipment in computer centre



Figure 2: Over toppled transformers



Figure 3: Mexico City Earthquake 1985

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 the systems. This 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 according to modern 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 particularly difficult for disaster types with longer return periods like earthquakes. An entire earthquake resilient infrastructural system is economically not feasible and 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.

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

There main principles to achieve an earthquake resilient infrastructural 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 are at risk if they are damaged 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 are at higher risk than decentralised systems with several interconnected control centres. In such systems redundancies are a must.
- Careful location of *new facilities* - 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 one of the most important principles. 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 an important 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 event on the economical and social conditions. Set priorities where and to which extend 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 taking into account regional and local geological and topographical effects as well as secondary hazards triggered by earthquakes.
- Assess infrastructural system vulnerability taking into account structural and functional aspects as well as redundancy and fast repair possibilities.

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