Earthquake Aspects of Infrastructure Projects

1 Earthquake effects

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 10 Hz. In general, the severity of the shaking 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 to predict short-term occurrence with any accuracy (location, size of earthquake and time of occurrence). The only possibilities are to reduce the effects by appropriate planning and construction measures.

In terms of human and economic looses seismic shaking is the most significant factor contributing to the overall earthquake hazard. Shaking contributes to losses not only directly through vibratory damages to man-made structures but also indirectly through triggering of secondary effects such as landslides or rockfall or other forms of ground failures (soil liquefaction, slumping, settlements etc.). 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:

(i) **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-, electricity- and sewer-lines. There exist also a number of dams, which have been built across faults, which are considered as potentially seismic active, today. Surface faulting can be particularly severe to structures partly embedded in the ground and for underground pipelines and tunnels. Surface faulting generally affects a long and narrow zone ranging from few meters to more than 100 meters. Secondary faults have extended as much as 10 km from the main fault and secondary faulting has been observed more than 25 km from the main fault. The length of ruptures can range from a few 100 meters up to about 400 km. Their size is important for zoning purposes around active faults. Moreover, the earthquake ground motion near active faults is different from that recorded at greater distance from the fault (directivity effects).

(ii) **tectonic subsidence and uplift** usually accompany 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 large parts of the earth crust. This local deformation can distort or tilt structures. Regional tectonic deformations constitute a hazard to shoreline facilities and hydraulic systems where changes in land elevation occur relative to the water level. Such changes can affect many hundred of square kilometres. In the 1964 Alaska Earthquake piers, docks, breakwater structures, roads, railways, airstrips, buildings were tectonically lowered relatively to the sea level resulting in permanent or intermittent inundation. In other areas tectonic uplift reduced the water depth in harbours and waterways restricting their use.

(iii) **Landslides, rockfall, avalanches**. Earthquake shaking can dislodge rock, and debris on steep slopes, triggering rockfalls, snow and ice avalanches. Ground shaking can initiate shallow debris slides on steep and less often rock slumps and rockfall on moderately steep slopes. Under certain geological conditions, shaking can reactivate dormant slumps or block slides. Avalanches can be triggered in weakly cemented fine graded materials , such as loess, that form steep stable slopes under static conditions. Even small water saturated sand lenses can trigger major landslides in nearly horizontal clayey deposits

(iv) **Liquefaction**. Areas having young layers (typically deposited during the past 10'000 years) of water saturated loose fine sands or silts can temporarily lose their strength and behave as viscous fluid due to severe ground shaking. Structures founded on such deposits settle, tilt or be ripped apart as the soil spreads laterally. Buried structures will float up. Ground shaking can cause lateral movements on top of liquefied surface layers. Such large subsoil deformations usually interrupt service lines (water, sewer, gas, electricity etc.) Due to soil liquefaction the port facilities of Kobe were out of service for several months due to the earthquake of February 1995. In the harbour area the entire water supply system failed due to liquefaction induced excessive subsoil deformations, hindering also fire-fighting activities.

(v) **Tsunamis**. A tsunami (Japanese word meaning harbour wave) consists of a series of waves of long length and period 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 length and height of the wave increases greatly reaching up to 30m.

(vi) **Seiches**. In lakes tectonic movements and rockfalls can induce long period water waves, which can spill low level shores or dams causing erosion damage.

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 occurrence with any degree of accuracy. Earthquakes affect large areas with various effects and producing enormous human and economic losses. They have therefore a significant effect on development of the whole country. Earthquake resilient infrastructure becomes a prerequisite for an effective disaster response and fast reconstruction activities after an event and for a 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 part of the overall sustainable development process of 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 story office building of masonry type in an earthquake intensity MSK XI). In a infrastructure system one has to distinguish between the system vulnerability and the vulnerability if each component (service lines, structures, control systems etc.). Conventional vulnerability assessment concentrates often only on structural vulnerability (damage to the structural system). But at least as important is the functional vulnerability. Functional vulnerability usually is higher than structural vulnerability. That means that functional failure precedes the structural failure. On the other hand functional vulnerability often can be reduced with very cost effective means.

Characteristics of infrastructure systems

All infrastructure-systems consist of structures (individual and/ interconnected structures), equipment, power-supply, control systems etc. One distinguishes mainly object-oriented systems (OS) as e.g. hospitals, police- and fire-station, central food-storage etc. and mainly network oriented systems (NS) as e.g. electricity-, gas-, water-, sewer-systems etc. The following types of infra structures systems are particular important in disasters::

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

The characteristics and individual importance of those systems and every individual of its component vary in every country from area to area.

Vulnerability of infrastructure systems

In a infrastructure-system not every structure, or subsystem has the same importance to maintain the functionality of the system. One also has also to keep in mind that in case of a disaster not every public service has to function to the same extent as in normal times, e.g. in time of emergency to maintain the public health system not every hospital has the same importance, very important are hospitals with emergency capacities. The responsible authorities of every infrastructure system has to define which services will be provided to what extent in what type of disaster. This so called "reduced mode" will vary from disaster type to type and it intensity. The system vulnerability has to be evaluated only in respect to maintain such reduced modes. To

carefully define reduced modes of services is a delicate political problem but very often of economic consequences.
Line based systems as water and power lines crosses wide areas with different geological and topographical conditions. Some of them will be often unfavourable, so local interruptions are inevitable. Such systems can be improved by introducing some form of redundancy. Redundancy will also improve the operational procedures in normal times. The behaviour of object-based systems depends heavily on the local site conditions. A careful site selection in respect to earthquake hazard is very important. Avoiding unfavourable site conditions (e.g. loose soil deposits, high water table etc.) is very effective in reducing the hazard. When strengthening is foreseen the influence on the level of shaking and the overall underground behaviour has to be evaluated very carefully. Experience shows that in practice this is very often neglected.

Vulnerability of infrastructure components

(i) Structures

Methods to assess the vulnerability of structures are well established. Experience from past earthquakes show that structures build according to modern codes, later than about 1980, will face limited damage. Methods also exists to assess sufficiently enough the behaviour of underground under strong shaking (e.g. liquefaction potential). At least some parts of infrastructures have also to fulfil serviceability criteria.

(ii) Mechanical and electrical components

There is less easily accessible experience for assessment of vulnerability for ordinary mechanical and electronic equipment under earthquake excitation.

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 reducing the vulnerability of the systems ranging from the physical protection, like constructing stronger buildings and strengthening existing structures, introducing redundancy in a system, to procedural, like introducing standard techniques for incorporating hazard assessment in land-use planning, preparation of disaster response and reconstruction plans etc. Building disaster-protection takes time. Remember in urban areas most of the infrastructure projects are not built to modern codes and quality assurance methods. In rural areas most buildings and part of infrastructure are non-engineered. To achieve an earthquake resilient infrastructure system, therefore, takes time and requires a continuous effort in planning better system resistance, maintaining or improving the system safety level and providing the necessary funding. This task is particular difficult for disaster types with longer return periods like earthquakes. To aim for an entire earthquake resilient infrastructure-system is usually economically not feasible and not reasonable. Therefore, a priority of real needs - based of careful defining the required reduced mode of the system, the evaluation of the importance of all system components to maintain the reduced mode, the assessment of the hazard taking into account local conditions and the vulnerability of the important component - is a must. Mitigation planning should aim to develop a "safety culture" in which all members of 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 are few main principles to achieve an earthquake resilient infrastructure-system:

(i) The design of service networks systems (transportation, water supply and sewer, energy supply (electricity, gas) or telecommunication) needs careful planning to reduce the systems failure. Long supply lines are at risk if they are cut at any point. Networks that interconnect and allow more than one route to any point are less vulnerable to local failures provided that individual sections can be isolated when necessary. Systems with central control facilities are at higher risk than decentralised systems with several interconnected control centres. In such systems redundancies are a must.

(ii) Careful location of new facilities - particular infrastructure systems but also community facilities like hospitals, schools etc. play an important role in reducing settlement vulnerability in urban areas. Aerial distribution of elements at risks is one of the most important principles. Earthquake zoning maps are basic tools for risk mitigation.

(iii) The linkage between different sectors of the economy may be vulnerable to disruption by the disaster. Diversification of the economy is an important way to reduce the risk of an economy break down in the aftermath of the event and thus reducing the capability of a fast recovery. A strong economy is the best defence against any type of disaster. Within a strong economy, governments are able to maintain a resistant infrastructure and to 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 the effects of large event in the area of investigation on the country economic and social conditions. Set priorities where and to which extend mitigation measures are mandatory.
- Define infrastructure-systems important for disaster response and reconstruction
- Define socially and economically acceptable reduced functionality of every infrastructure-systems
- Assess carefully hazard taking into account regional and local geological and topographical effects as well as secondary hazards triggered by the earthquake
- Assess infrastructure-system vulnerability taking into account structural and functional aspects as well as redundancy and fast repair possibilities.

References

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