The mitigation of secondary seismic hazards in urban areas through the planning process with examples from Tangshan and Beijing, China

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Abstract: For many years cities have grown in seismically active areas throughout the world often without realising the potential for devastating earthquakes to affect them. There is now a high level of understanding of the risks that they face and recognition that there is little prospect of the accurate forecasting of seismic events other than the inevitability of their occurrence. The cities cannot be moved because of the enormous investment in infrastructure that they represent. However, mitigation of the risk can be achieved, in part, through the planning process applied during development and redevelopment. In this paper the nature of the planning process is briefly discussed and the way it can be used to mitigate the effects of an earthquake is described. An example of how this has been implemented in north-east China during the redevelopment of the city of Tangshan after the destruction caused by an earthquake in 1976 is presented. Examples of how such an approach might be applied and in the rapidly growing city of Beijing, China is also presented.

Résumé: Depuis de nombreuses années, des villes se sont développées dans des zones ayant des activités sismiques, et ce dans le monde entier, souvent sans se rendre compte du potentiel de tremblements de terre dévastateurs pouvant les affecter. Il y a désormais un haut niveau de prise de conscience des risques que ces villes doivent confronter et il est admis que la prédiction exacte des événements sismiques autre que l'inévitabilité de leur apparition est peu probable. Il est impossible de déplacer les villes en raison des énormes investissements d'infrastructure qu'elles représentent. Toutefois, une atténuation du risque est possible, en partie par le processus d'urbanisme appliqué au cours des périodes de développement et de redéveloppement. Cet article aborde brièvement la nature du processus d'urbanisme et décrit la façon dont il peut être utilisé pour atténuer les effets d'un tremblement de terre. L'article donne un exemple sur la façon dont ce processus a été mis en œuvre dans le nord-est de la Chine lors du redéveloppement de la ville de Tangshan après la destruction causée par un tremblement de terre en 1976. On a également cité des exemples de mise en application d'une telle approche à San José au Costa Rica et dans la ville en pleine croissance de Beijing en Chine.

Keywords: earthquakes, geological hazards, geology of cities, planning, seismic response.

INTRODUCTION

In 1989, in the 2nd Mallet-Milne Lecture on "Coping with natural hazards: the International Decade for Natural Disaster Reduction," Professor George Housner stated that the "main goal of an earthquake hazard reduction program is to preserve lives through the economical rehabilitation of existing structures and the construction of safe new structures." (Housner 1989). To achieve this end he suggested that a number of projects should be initiated, including "avoidance, through zoning, of construction on vulnerable sites...." In these two observations, Housner identified two ways in which damage to buildings and structures can be reduced in an earthquake: first, by rehabilitating existing structures and building better new structures to resist earthquake effects and second, by avoiding particularly vulnerable sites; this is done by identification of how the ground will respond to an earthquake and subsequent zonation. In terms of the hazards that result from earthquakes, such zonation requires an understanding of the geology of a site, area or region, as well as the seismicity. For urban areas, the availability of large quantities of subsurface data (from boreholes) and the rapid developments in computer technology mean that, in the future, this geological understanding can be based upon three dimensional models rather than two dimensional maps (Culshaw 2005). This paper addresses the ground response to earthquakes, secondary seismic hazards, and how their consequences may be minimised through the planning process with examples from the Chinese cities of Tangshan and Beijing.

The distribution of hazards triggered by primary earthquake ground motion is dependent upon the ground conditions. These can be termed secondary seismic hazards and include:

- liquefaction
- ground motion amplification
- landslide
- ground rupture/ground level change (including ground subsidence/collapse)
- tsunami

LAND USE PLANNING

The aim of a land use planning system in a country is to ensure a safe environment for the population and that resources are used in a beneficial way and not squandered, spoiled or overlooked and that the environment is conserved or protected. Resources may include assets such as mineral deposits, potable water, forest or good agricultural soil. Environmental protection may include areas of scenic beauty, clean air and unpolluted water supplies. In this way, the economic and physical health of the community is protected and its future wellbeing is ensured. The objectives of planning are that development should be beneficial to the community, it should be cost effective, it should achieve and maintain a safe, pleasant environment and that the environment and economic activity should be sustainable.

Planning systems may vary from highly prescriptive regimes, where everything is forbidden unless specifically permitted to more lax systems where everything is permitted unless specifically forbidden. In practice, most systems adopt a moderate position between the extremes. Planning systems usually contain three aspects in their operation.

Forward planning

Forward planning considers the strategic requirements of a country in order to create the infrastructure within which development can proceed, to indicate where particular land uses should be situated, and to set the criteria on which development applications will be judged.

This aspect of planning is concerned with a wide range of activities such as:-

- Utilities - electricity, gas, water.
- Industry - factories.
- Commerce - shops, offices.
- Mineral resources - mines, quarries, gas and oil.
- Leisure - sport, entertainment, parks, open space
- Transport - road, rail, water, air.
- Community needs - houses, flats, schools, hospitals.
- Waste disposal - landfill, incineration, sewerage.

Planning control

Planning or development control is the planning process by which permission is given or denied for a development, or land use, to go forward. Initially, it is concerned with the compatibility of a construction, use, or change of use, of a site, with the land use as designated in the forward plan for the area. If this is deemed to be acceptable then the process moves forward to the next consideration, which is whether the proposed construction has been designed to suitable standards with regard to its function and its interaction with its surroundings. This requirement is set out and described in technical specifications in building or construction codes which deal with considerations such as:

- Fire safety - inflammability, escape routes, fire service access.
- Quality of construction - foundation design, building design, materials, cladding, insulation, roofing.
- Health - minimum space requirements, ventilation, sanitation.

For decisions to be made as to the safety and suitability of a structure and its foundations, criteria have to be established that set minimum standards of construction related to the function of the building and the local environment within which it has to fulfil its function. These criteria have to be observed and may be set out at the national level in general terms but may need to be modified to meet local conditions such as climate or geology.

Building control

The third aspect of planning is implementation and enforcement. Where structures are built without planning consent the planning authorities have a duty and may have the right to have them removed. Where the required construction standards are not met, then the authorities are able to enforce them and make the builder comply with the standards. If the planning regulations are not enforced then the planning system breaks down with a consequent reduction of public safety and a deterioration of the environment.

To achieve this function, it is essential that the regulations relating to construction are made available to those involved in the design and construction of buildings and that familiarity with them is made part of the training of such people. During construction inspection by agents of the building control authority must be made to ensure that the standards are met by all parts of the structure, particularly those parts, such as foundations, which will be hidden by later phases of the construction process.

Emergency planning

Emergency planning is a specialism within planning, which seeks to identify the consequences of potential hazards and to make provisions within the planning system and the community to mitigate the effects of these events should they occur. Provisions might include stocks of food, medicine and temporary shelter. As well as physical precautions, a programme of public education may be desirable to raise awareness of the hazard and the steps that the population should take at its onset to minimise its effects. For example, in the event of a tsunami, not only is there a need for a advance warning system, but communication systems need to exist to transmit the warning, people need to be trained how to react to the warning and escape routes and safe locations need to identified and signposted.

SEISMIC HAZARD MITIGATION AND THE PLANNING PROCESS

To reduce the risk from secondary seismic hazards, it is necessary to obtain an understanding of the geological processes that control them and of the distribution of the geological strata that are susceptible to each hazard. It is then possible to assess the level of hazard so that structures can be located in areas where the degree of hazard is lower. If structures must be placed in specific locations then the engineer can be made aware of all the potential secondary seismic hazards that may affect the structure and take account of them in the design.

To achieve this, a methodology is required for the assessment of secondary seismic hazards in urban planning. This methodology is concerned with the development of policies or procedures to integrate technical information on geological hazards into national land use plans, urban and coastal zone planning and site planning (Culshaw et al. 1995). There are three definite scales to these procedures:

- Land use planning is usually undertaken at the national and regional scales to designate zones for different types of development with a view to producing a balanced urban environment.
- Urban and coastal zone planning is usually undertaken at the regional and metropolitan scales to fine-tune the individual development zones by accounting for local ground conditions and other social, economic and environmental factors.
- Site planning is undertaken at the site scale to maximise the potential of a development while minimising its exposure to a geohazard.

The planning process at each level requires a consideration of how a geohazard will affect the proposed development. This assessment methodology should have a modular form such that it can begin and end at any scale of the planning process. To be practicable, the hazard assessment methodology has to integrate into the planning process by providing a formalised structure, allowing decisions to be made about hazards, which are appropriate to the scale at which the planning is being undertaken. This requires decisions on:

- At the national and regional scales: whether an area is susceptible to a particular hazard or not. *What is the Hazard Potential?*
- At the regional and metropolitan scales: what hazard will occur and where it is likely to occur? *What are the Hazard Conditions?*
- At the site scale: what is the extent of the hazard, and consequently, what problems it will cause (and how does this affect the site elements)? *What are the Site Problems?*

This can be satisfied by a modular assessment methodology that operates at the same three scales as the planning process. The planning decisions at the respective scales are addressed as follows:

National/regional scales: the first step of a hazard assessment methodology is to identify the potential for a hazard to occur. This requires a zonation showing regions of, for example, low, medium and high susceptibility to hazards based on simple criteria, which provides a first-look map of hazards at the national/regional scales. Ultimately, the hazard susceptibility maps help a planner decide if there is a high potential for a hazard to occur and, subsequently, whether they should undertake the next, and more detailed, part of the hazard assessment.

Regional/metropolitan scales: the second step is to identify the hazard conditions and subsequently where a particular hazard will occur. This requires more detailed assessments demonstrating how and why certain areas are susceptible to a hazard. It involves the consideration of a set of interacting factors, with decisions made in a very specific order. That is, they are prioritised to form a systematic and consistent hazard evaluation. A means of achieving orderly decisions is to build them into a flow chart that establishes a priority of their importance and the order in which they should be considered. Ultimately, the flow charts warn a planner of the particular localities where certain hazards are likely to occur and that, in these areas, a thorough ground investigation is required to analyse the problems the hazards will impose on engineered structures.

Site scale: the final step is to incorporate the hazard assessment results into a site plan. This requires an analysis of the extent of each hazard, the problems it will impose on engineered structures and the necessary design improvements required to resist these. This will be achieved by a ground investigation being undertaken by an engineering geologist or geotechnical engineer.

SEISMIC HAZARDS AND PLANNING IN CHINA

China's policy regarding dealing with the problem of earthquakes is set out in "The law of the People's Republic of China on Protecting Against and Mitigating Earthquake Disasters" (Order number 94, Anon. 1999) that came into force on 1 March 1998. Article 22 states that *"The competent administrative department for seismic work under the State Council and the administrative departments or institutions for seismic work under the local people's governments at or above the county level shall, together with the departments concerned at the corresponding level, work out plans for protecting against and mitigating earthquake disasters on the basis of the prediction of the possible earthquake situation and earthquake disasters and put them into effect upon approval of the people's government at* *the same level."* Thus, the responsibility of local government to take earthquakes into consideration in the planning process is clearly stated. Elsewhere, secondary seismic hazards, such as landslides, are included in the hazards to be considered.

Construction in China is controlled by Building Codes, which are compiled at the National level by expert representatives from technical organisations from all over China and are revised every 10 - 15 years. The National Codes are not comprehensive but are minimum standards to which all construction must comply. Additional regulations may be added by local authorities to take into account local conditions and their implications with regard to local building requirements.

The city of Tangshan, in north-east China, was destroyed by a major earthquake (magnitude 7.8) on 28 July 1976. Hundreds of thousands of people died and the city was largely destroyed (Anon. 1988). In the case of Tangshan, the recognition after the 1976 earthquake that it was in a seismically active area required the addition of regulations regarding safe construction to minimise its vulnerability to seismic events. Local additions to the national code were drawn up by local experts with expertise drawn from organisations outside the city, as necessary. The Tangshan local codes were devised with assistance from, among others, the Comprehensive Institute of Geotechnical Investigation and Surveying (CIGIS) who prepared a report (Fang Hong-Qi and Wang Zhong-Qi 1981) and contributed advice on the assessment of building damage and replacement costs to a report by the Hebei Geological Survey (Ministry of Geology and Mineral Resources) (Anon. 1991). The 1991 report superseded the 1981 CIGIS report and was more specific regarding Tangshan city and its development areas.

The recent history of Tangshan gives an exceptional example of the effects of a major earthquake and the way in which forward planning and building control can be implemented to minimise the effects of future earthquakes.

THE TANGSHAN EARTHQUAKE

The city of Tangshan has a population of seven million and occupies an area of 13,000 km^2 divided into ten districts. It is a major centre of heavy industry and coal mining on the northern edge of the North China Plain, south of the Yanshan mountain range in north-eastern China (Figure 1)

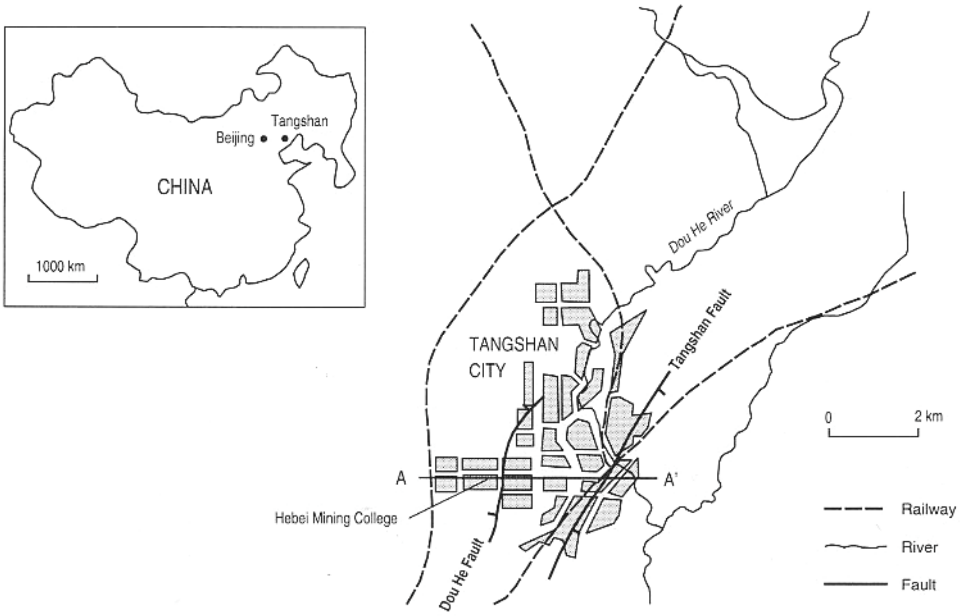

Figure 1. The City of Tangshan is located between the Dou He and Tangshan Faults in north east China.

The greater part of the city is underlain by thick alluvial deposits, which comprise various combinations of clay, silt, sand and gravel. The superficial deposits cover an irregular bedrock topography of Ordovician limestone and Permo-Carboniferous sandstone, shale, and coal. A series of hills of weathered and eroded bedrock are present in the central and northern districts of the city where they have been uplifted between the Tangshan and Dou He River Faults. The Tangshan area lies at the intersection of two fault systems, the east-west trending Yinshan-Yanshan belt and the north north east trending Ji-Liu fault system. The City, itself, lies on the north east-south west trending Tangshan and Dou He River Faults (Figure 1).

The 1976 earthquake was caused by movement of the Tangshan Fault. Almost all the buildings in Tangshan were destroyed by shaking which was intensified, in many areas, by ground motion amplification due to thick superficial deposits and buried topographic effects (Forster et al.1996). In the vicinity of the active faults, ground fissuring caused much damage as did landslides along the banks of the Douhe River and liquefaction in the surrounding area. The total number of deaths remains uncertain but it was at least 240 000 (Anon. 1988). The number of those injured was estimated to be about 700 000 and the economic loss was estimated at around $2 bn (Anon. 1996).

PLANNING IN TANGSHAN

Forward planning

Before the 1976 earthquake, geological information was not taken into account in the construction of the city for earthquake resistance in its buildings or for the evacuation of survivors because it was not considered to be a seismically hazardous area. However, after the earthquake a major effort was necessary to reconstruct the city and earthquake resistant performance was taken into account with regard to site selection, building design and construction quality. This included consideration of engineering geological factors in the reconstruction (Fang Hong-Qi and Wang Zhong-Qi. 1981). Emphasis has been placed on planning in earthquake prone cities as a continuing process with strategic significance rather than a sporadic response to temporary concerns over the earthquake resistance of individual structures.

Before 1976 Tangshan was divided into an eastern mining district and a western urban area comprising two districts, Lubei to the north and Lunan to the south. After the 1976 earthquake a new urban structure plan was created which took into account geological factors, which would mitigate the damaging effects of future earthquakes. The Tangshan structure plan divides the City into six areas depending on the intensity level of the 1976 earthquake. In areas of intensity 8 or above, decisions are made as to what buildings are permitted.

The new city of Tangshan has met the threat of future earthquakes by three strategies:

- relocation,
- duplication,
- resistance.

Relocation

The most severe damage in the 1976 earthquake was experienced in the south east of the city in the intensity 11 area associated with the causative Tangshan fault. This area was scheduled for reconstruction with an emphasis on recreational open space, light industry and warehousing. Residential areas were concentrated in the western part of the city where geological conditions are better and groundwater levels are low. During the earthquake the Lunan district, which was close to the Tangshan fault, was particularly severely damaged and the 60 000 people who had been living in the $8km^2$ area of the Lunan district around Middle School 10, very close to the junction of two active faults, were moved to a new district in the west of the city, which suffered only slight damage in 1976. Accommodation usually is provided as flats in four or five story blocks with occasional six storey blocks separated by wide access roads with ample provision of open space (Fig. 2). The administrative areas of local government, business and other offices include cultural and sporting facilities and have been placed centrally in the western urban area. The move to the west had the added advantage of moving away from the old industrial areas with their problems of mining subsidence and pollution.

Figure 2. Tangshan was rebuilt to resist the effects of earthquakes and to allow access for rescue in the event of damage to buildings

Industry has been concentrated in the eastern areas separated from the western residential areas by Dacheng Hill. Although the area is not as low in terms of seismic hazard as the western area, the siting of industry is constrained, to some extent, by the need to be close to the coal mines. However, secondary seismic hazards are taken into account in the placing of industrial facilities. Particularly hazardous industries, such as chemical engineering or those using radioactive materials, and storage facilities for inflammable, poisonous or explosive materials, have been removed from urban areas to low hazard locations. Some light, non-polluting industries such as electronics or food processing are sited on the western fringe of the residential zone.

The main railway line from Beijing to Shanhaiguan, which was close to the line of the Tangshan Fault, and the Tangshan Railway Station were relocated into a lower hazard zone to the west of the city, a decision that was also influenced by the need to gain access to the 600 000 000 tons of coal, which lay beneath the old station and associated railway lines.

In addition to the reorganisation and reconstruction of Tangshan, some major industries, factories and populations were moved out of the city to create new satellite cities at Fengren and Guye some 25 km distant from Tangshan. Other large industrial plants and mines, which were originally on the periphery of Tangshan, were developed to form the focus of small industrial towns. In this way the population and associated vulnerable structures were decentralised and the risk of damage spread over a wide area.

Duplication

Lifeline and service protection was given a high priority in the new plan and geohazard factors were taken into account. New roads out of the city were built on safe ground and old roads were rerouted to safer ground or designed to be earthquake resistant. A water supply ring main was installed connected several independent water sources and supply works. A similar ring main was used for the distribution of electric power and the four electric power generating stations located in the cities of Beijing, Tangshan and Tianjin were connected by 220 00 volt high tension transmission line to maintain power distribution within the region in the event of earthquake damage. Emergency supplies of gas, food and medical supplies were stored in a number of safe areas.

Resistance

The Dou He River Dam was reinforced to withstand a 1000-year event without failing. The consequence of failure would be a devastating flood, which would result from the release of the impounded volume of 400 000 000 m^3.

Ground motion amplification is a serious problem where the cover of superficial deposits is very thick, such as the site of the Hebei Mining College where it is 250-350 m thick. The college was totally destroyed in 1976 and the amplification by the sediment cover was aggravated by the presence of a steeply dipping, buried, bedrock/superficial deposits interface (Forster et al. 1996, Hou Ming-zhong 1981). However, since it was considered desirable to rebuild on the same site, close to the urban centre, it was reconstructed with buildings of strengthened design and fewer storeys to resist earthquake forces. Where the cover is less than 50 m thick ground motion amplification is very slight

Building control

Building control starts on the assumption that the area is subject to magnitude 8 earthquakes. Geotechnical tests are required on a site-specific basis to determine the site response to earthquake shock and the buildings are designed for a magnitude 8 earthquake taking into account the site's response. All building designs must comply with the National Building Codes, as amended locally, and be approved by the Earthquake Resistance Office, which supervises and monitors construction projects. If they find codes have not been followed they can impose fines.

Wide spaces are left between buildings so that, should they collapse, a clear pathway will be left between them for access by the rescue services. In general, two to six storey buildings will spread out to two thirds of their height. Ample provision of open space is left to allow refuge for survivors and room to operate rescue services.

In the central area, building is forbidden on the river banks of the Dou He River, where soft sediments are prone to landsliding and liquefaction, to a distance of 100 m either side. Where buildings were present in this zone, their foundations were enlarged to reduce the ground loading and their structure was reinforced. Where construction is carried out close to the exclusion zone boundary, ground improvement is carried out by densification with 10 tonne rammers. A similar 100 m exclusion zone is maintained either side of active faults.

Special regulations apply to ground improvement for foundations in areas of karst and where buried river channels are present. Building may be permitted in areas subject to liquefaction but only if special foundations are used.

SEISMIC PLANNING IN BEIJING

The city of Beijing lies 150 km to the west of Tangshan on the north-west margin of the North China Plain. Beijing lies between the Yongding and Chaobai Rivers and is founded on alluvial fan deposits laid down on predominantly Palaeozoic bedrock by them. The plain dips gently from north-west to south-east providing an, apparently, ideal environment for urban development.

Engineering geological background

The Pre-Tertiary rocks are overlain by a complex covering of superficial deposits which form proluvial cones, river terraces, loess terraces, piedmont slopes and comprise coarse sandy gravels and cobbles near the mountains grading to sandy clays interbedded with cobbles towards the plain and clays, silty fine sands in the plain (Figure 3). Soft, loose recently deposited alluvium, compressible soils and anthropogenic deposits are present locally.

An engineering geological investigation department was set up by the Municipality of Beijing in 1951. Its aim was to obtain hydrogeological, engineering geological and environmental data relevant to urban planning and construction. Initially, it studied the groundwater regime beneath the city and installed a series of long-term groundwater observation wells. It presented its findings as a series of maps and reports. Between 1955 and 1961 a series of engineering geological studies were completed. These included a systematic investigation with boreholes to a depth of

6 - 10 m on a grid of about 500 m spacing which formed the basis for engineering geological zoning maps of the city at a scale of 1:2 000 and technical maps at 1: 50 000 scale. This work was extended outward from the city, into the plain, to produce preliminary and detailed engineering geological maps for satellite towns at scales of 1:10 000 and 1:2 000 respectively. Thus, a detailed engineering geological background was established to assist decisions on land use and planning. More recently, a digital engineering geological information system has been created, linked by a local area network, which has incorporated over 50 000 site investigations and more than 500 000 borehole logs. This very large data set, together with the advanced data handling facilities of the computer, have enabled a more effective contribution to urban planning and construction to be made.

Seismicity

Although Beijing was known to be in a seismically active area in which over 180 earthquakes had been recorded, the Tangshan earthquake of July 28th 1976, with an intensity of VI in most parts of the Beijing plain area, was the first earthquake above Magnitude 5.0 to affect the city since 1730 (Table 1). It caused severe damage to buildings in the eastern and south eastern part of the plain area; damage was also sustained in the western area and least damage was caused in the centre of the city. Liquefaction occurred in areas of intensity VII leading to ground fissuring, subsidence, lateral spreading and sand boils. This event emphasised the need to include seismicity as a factor in land use planning and procedures similar to those in Tangshan were instigated.

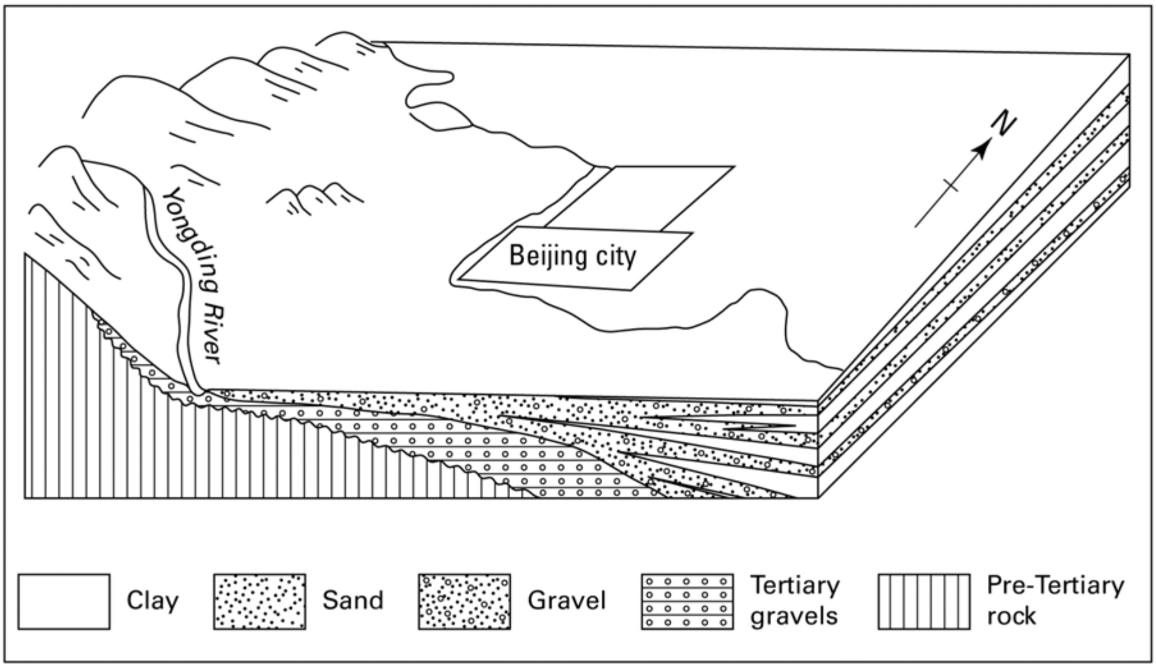

Figure 3. Geology and geomorphological setting of the city of Beijing (after Yuan Binglin et al. 1994).

Local effects

Observation of the effects of the Tangshan and previous earthquakes showed that the local geology was a major control on the effect of an earthquake at a particular location. Damage to structures founded on bedrock in the mountainous area was less than damage to structures founded on thick superficial deposits in the plain area due to the amplification of the ground motion as it moved from high velocity bedrock to low velocity superficial deposits. Active faults caused local fissuring and, if they were the causative fault, the earthquake intensity was high close to them. Topographic effects increased damage by focusing the earthquake wave or increasing its effect by constructive interference. Liquefaction only occurred on loose saturated silts and clays.

Planning response to local effects

The seismic response curves were produced at a number of sites in, and near to, Beijing City to determine the potential for ground motion amplification (Figure 4). It was established that the maximum acceleration at the ground surface in the western area, where bedrock was close to the surface, was greater than 0.2 m/sec^2; in the central and south east, where superficial deposits were thick, it ranged from 0.1 – 0.2 m/sec^2 and in the north east, where superficial deposits were thick and soft, it ranged from 0.05 – 0.1 m/sec^2.

The consequence of this for the planning process is that low rise buildings of short structural periods should be avoided in the western area because they would be subjected to large seismic forces, whereas high rise buildings of long structural periods in the eastern area would be subjected to even higher forces than in the west.

Three active faults were identified in the Beijing area, the Huanzhung-Gaoliying Fault, the Nankou-Sun River Fault and the Xiadian-Mafang Fault. Major construction projects are not placed on, or near to, these faults The

Number 9 Water Supply Plant, which is the largest water supply plant in Beijing, was originally to be constructed near to an active fault but was subsequently constructed at an alternative site when the hazard caused by the fault was realised. Buildings are placed away from mountain ridges, hilltops, steep slopes, river banks and dams to avoid topographic effects.

Liquefaction is associated with poorly densified, saturated, sands and silts, most of which occur as deposits around the courses of modern and ancient rivers. Construction in these areas is subject to compulsory technical investigation to determine the economic feasibility of constructing on such a site and, in general, such sites are left as open spaces. In many areas around the city these areas are used for market gardens and agriculture.

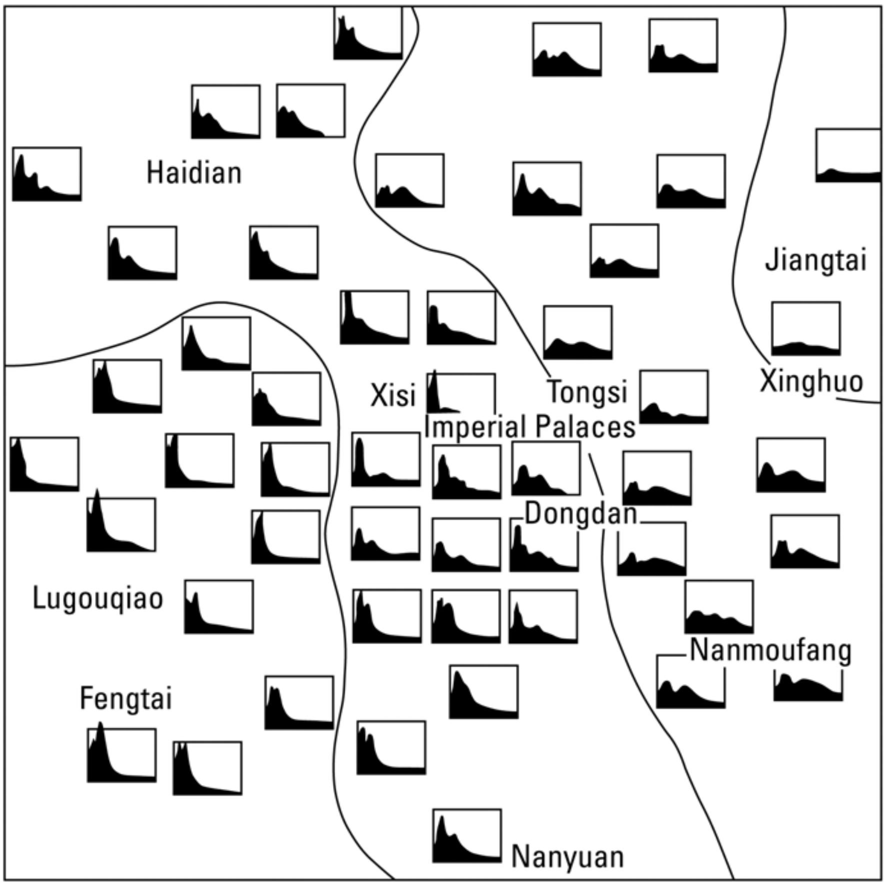

Figure 4. Distribution of seismic acceleration response spectrum curves in, and near to, the city of Beijing showing a gradual increase in period of vibration and decrease of peak ground acceleration of soil layers from the southwest to the northeast (after Chen Qingxuan et al. 1987).

Table 1. Historical earthquakes affecting the Municipality of Beijing (after Yuan Binglin et al. 1987)

Date	Magnitude	Location of epicentre	Damage recorded
May 1057	6.8	Near Beijing	City walls and temple destroyed, many deaths.
December 1076	5.0	Beijing	Most houses damaged or destroyed.
September 1337	6.5	Huailai	Temple beams and columns damaged.
January 1484	6.8	Juyongguan	Walls collapsed, liquefaction, deaths.
October 1536	6.0	Tong County (south)	Houses collapsed.
February 1627	5.0	Beijing	Houses collapsed, many injured.
April 1665	6.5	Tong County	City walls, houses and temples destroyed.
September 1679	8.0	Sanhe-Pinggu	Temples, houses, pagodas destroyed. Ground fissures.
July 1720	6.8	Shacheng	Houses collapsed, many deaths.
September 1730	6.5	Near Beijing	Temples and 50% of houses collapsed. City walls cracked.
July 1976	7.8	Tangshan	Houses, buildings, Bai River Dam and many bridges damaged. Liquefaction.

CONCLUSIONS

To effectively reduce the risk of death, damage and injury resulting from major earthquakes it generally is accepted that a duel approach is required involving structural engineering and land use planning. The approach can be summarised as ‘relocation, duplication and resistance.’ To enable architects and structural engineers to design and construct more resistant buildings requires information on the probable size and nature of likely future earthquakes, as well as information on the geological nature and geotechnical and geophysical properties of the ground. Planners, on the other hand, need information about the likely *effects* of future earthquakes, rather than information about the earthquakes themselves. So, the susceptibility of any urban area to the secondary hazards of earthquake occurrence, namely liquefaction, ground motion amplification, landsliding, ground rupture/ground level change and tsunami, are much more important for land use planning. These are controlled mainly by geology and geomorphology. The importance of understanding these secondary effects, and planning for them, is important because it is still impossible for scientists to predict the magnitude, location and timing of damaging earthquakes.

The adoption of such an approach in China following the devastating Tangshan earthquake of 1976 illustrates how taking account of secondary seismic hazards has been fully incorporated into the planning process both in Tangshan and Beijing. Particularly hazardous areas are avoided for construction, the areas being left as open space. Buildings are located well apart to ensure access is available for emergency services, even if buildings collapse; services and lifelines are duplicated and new buildings are constructed to higher standards to enable them to resist future earthquakes. This approach was only brought about by the disaster of 1976. However, the lessons learnt are applicable to most cities in the developed and developing world, where geological hazards (whether from earthquakes or other geological processes) threaten human safety and economic viability.

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REFERENCES

ANON. 1988. The great Tangshan earthquake of 1976, an anatomy of disaster. CHEN YONG, KAM-LING TSOI, CHEN FEIBI, GAO ZHENHUAN, ZOU QIJIA AND CHEN ZHANGLI (eds). Pergamon Press, Beijing.

ANON. 1991. Central Tangshan - Engineering geology mapping report. Hebei Geological Survey, Ministry of Geology and Mineral Resources, 15 maps, pp.88. (In Chinese)

ANON. 1996. Manual on environmental and urban geology of fast-growing cities. Atlas of Urban Geology, Volume 9. Economic and Social Commission for Asia and the Pacific, United Nations, New York.

ANON. 1999. ‘The law of the People’s Republic of China on Protecting Against and Mitigating Earthquake Disasters’, Order of the President of the People’s Republic of China Number 94. China Seismological Bureau.

CHEN QINGXUAN, SUN YE AND ZHENG WENQU. 1987. Seismicity and tentative seismic hazard zonation of Beijing and vicinity. Report of The International Working Group on IGCP project 250 'Regional crustal stability and geological hazards'. Institute of Geomechanics, CAGS, Beijing, China. 36-43.

CULSHAW, M. G. 2005.From concept towards reality: developing the attributed 3D geological model of the shallow subsurface. *Quarterly Journal of Engineering Geology and Hydrogeology*, **38**, 231-284.

CULSHAW, M. G., GUNN, D. A., FORSTER, A. AND JACKSON, P. D. 1995. Assessment of secondary seismic hazards for urban planning: a geological perspective. British Geological Survey Report No. WC/95/25. British Geological Survey, Keyworth, Nottingham.

FANG HONG-QI AND WANG ZHONG-QI. 1981. "Approach to Tangshan Earthquake Engineering Geological Problems". Report of Building Research No. 30, Geotechnical Investigation Institute, Chinese Academy of Building Research, People's Republic of China. 355 p.

FORSTER, A., JACKSON, P. D. AND XIANZHONG LI. 1996. Ground motion amplification: an example from the city of Tangshan, China. *Quarterly Journal of Engineering Geology*, **29**, 97-101.

HOUSNER, G. W. 1989. Coping with natural disasters. The Second Mallet-Milne Lecture. Society for Earthquakes and Civil Engineering Dynamics, London.

MIN-ZHONG HOU. 1981. Reconstruction planning for Tangshan City after 1976 Tangshan Earthquake. *Proceedings of the Sino-American workshop on: "Earthquake disaster mitigation in urban planning,"* Beijing.

YUAN BINGLIN, YAO BINGHUA AND ZHOU RUZHONG 1994. Urban construction and geological environment Beijing. In: Wang Sijing, Wang Cunyu and Shao Xingya (eds), *Proceedings of the International Conference on Geoscience in Urban Development (Landplan IV*), Beijing. China Ocean Press, Beijing. 109-127.