SEISMIC HAZARD ASSESSMENT

Introduction

This annex presents a summary of the Seismic Hazard Assessment for the eight WTWs which was undertaken by Ove Arup (2000). The following paragraphs summarise the work which has been undertaken and the application of the results of the Seismic Hazard Assessment in the QRA.

Scope of Work

The work undertaken by Ove Arup investigated the seismic vulnerability of the chlorine stores at the eight WTWs and advised on the magnitude of earthquake necessary to cause varying levels of damage, from relatively minor, 'internal' damage to gross collapse of the store. The focus of the work was on the consequences of earthquakes in terms of the potential release of chlorine, whereas the likelihood of an earthquake of a given magnitude was derived from the *Daya Bay Risk Assessment* study (Cook et al, 1993), which has been used in past Hazard Assessment studies of WTWs in Hong Kong. Apart from advising on the likely damage to the chlorine stores at the eight WTWs, part of Ove Arup's scope of work was also to advise on the likely levels of damage to the general building stock in Hong Kong. This assists in determining the marginal impact of an earthquake on the surrounding population.

Methodology

The methodology for the Seismic Hazard Assessment involved:

- qualitative evaluation of the seismic vulnerability of the chlorine stores against the Federal Emergency Management Agency (FEMA 273) 'checklist';
- review of damage surveys from earthquakes around the world (including assessment of their relevance to structures in Hong Kong); and
- modelling of the dynamics of objects impacting chlorine containers.

Key Findings of Seismic Hazard Assessment

The key findings of the Seismic Hazard Assessment are as follows:

- the outcome of a earthquake of a given magnitude is probabilistic in nature rather than deterministic and graphs have been provided by Ove Arup (derived from historical data) which can be used to determine the probability of a given level of damage for an earthquake of a given magnitude;

- the chlorine stores at the eight WTWs may be divided into three groups, according to their vulnerability to seismic loading:

- *Group 1* (Sha Tin, Pak Kong, Au Tau) being the least vulnerable and ranking amongst the best buildings in Hong Kong;

- *Group 2* (Sheung Shui and Yau Kom Tau) being of average vulnerability but above average when compared to the general building stock (equivalent to high rise buildings of more than 20 storeys); and

- *Group 3* (Tuen Mun, Tsuen Wan and Tai Po Tau) being the most vulnerable, equivalent to the average vulnerability of the general building stock in Hong Kong (ie low rise buildings up to 10 storeys in height).

• there is no 'partial' failure mode of the chlorine buildings, ie due to their nature of construction (reinforced concrete) they will either fail catastrophically or not at all;

• the magnitude of earthquake required to cause gross collapse of the chlorine stores is large, eg for a probability of collapse of 50%, the required magnitudes of earthquake (peak ground acceleration) are 1.0g/MMXII (*Group 1* WTWs), 0.80g/MMXI-XII (*Group 2* WTWs) and 0.60g/MMX-XI (*Group 3* WTWs);

• the potential consequences of a roof collapse are severe due to the heavy construction of the roofs at the eight WTWs (roof slabs are typically 200mm thick and roof support beams typically 300mmx500mm in cross section). The predicted number of drums which would fail catastrophically is typically 10-100, depending on the WTW under consideration.

Modelling of Seismic Hazards in the QRA

The assessment of seismic hazards in the QRA for Yau Kom Tau WTW focuses on earthquakes which could cause roof collapse leading to multiple catastrophic failure of chlorine drums. Two magnitudes of earthquake are considered: 0.5g/MMX (10% chance of roof collapse) and 0.8g/MMXII (50% chance of roof collapse) as shown in *Figure G1* (Ove Arup, 1999).

Within the QRA two key aspects are modelled:

• *the impact of the earthquake on the chlorine store*, in terms of the probability of roof collapse, probability of damage to chlorine containers and number of containers failing; and
• *the impact of the earthquake on the buildings surrounding each WTW*, in terms of the % of buildings of different types which would be expected to fail (this information is used to estimate the number of direct fatalities due to the earthquake, hence the surviving fraction which could be exposed to the chlorine release). .

Figure G2 summarises the modelling of seismic hazards in the QRA for Yau Kom Tau WTW in the form of an event tree showing the various outcomes of earthquakes of magnitude 0.5g (MMX) and 0.8g (MMXI-XII).

In *Figure G2* the 'surviving fraction of the indoor population' calculated in the last column is used to modify the population data (*Table 4.2* of the main text of the report), so that only the *additional* fatalities due to the chlorine release are assessed. For outdoor populations within high-rise, urban areas a fraction (50%) of the outdoor population is also assumed to suffer direct fatality due the earthquake, ie through falling masonry.

A summary of the drum impact assessment is shown in *Table G1* below (Ove Arup, 1999):

Table G1 *Evaluation of the Damage of the Chlorine Containers for Collapse of Building Structures*

Site Name	Sheung Shui	Au Tau	Tuen Mun	Yau Kom Tau	Tsuen Wan	Tai Po Tau	Pak Kong	Sha Tin
Type of Container	Drum	Drum	Cylinder	Drum	Cylinder	Drum	Drum	Drum
Number of Container	50	60	700	60	580	20	150	203
Minimum number of drums ruptured	0 (25)[1]	4 (25)	25 (25)	8 (25)	15 (25)	6 (50)	10 (25)	35 (25)
Intermediate number of drums ruptured			40 (50)		30 (50)		25 (25)	40 (25)
Maximum number of drums ruptured	7 (75)	8 (75)	55 (25)	12 (75)	45 (25)	8 (50)	115 (50)	47 (50)

Note 1: Likelihood (%) of effect

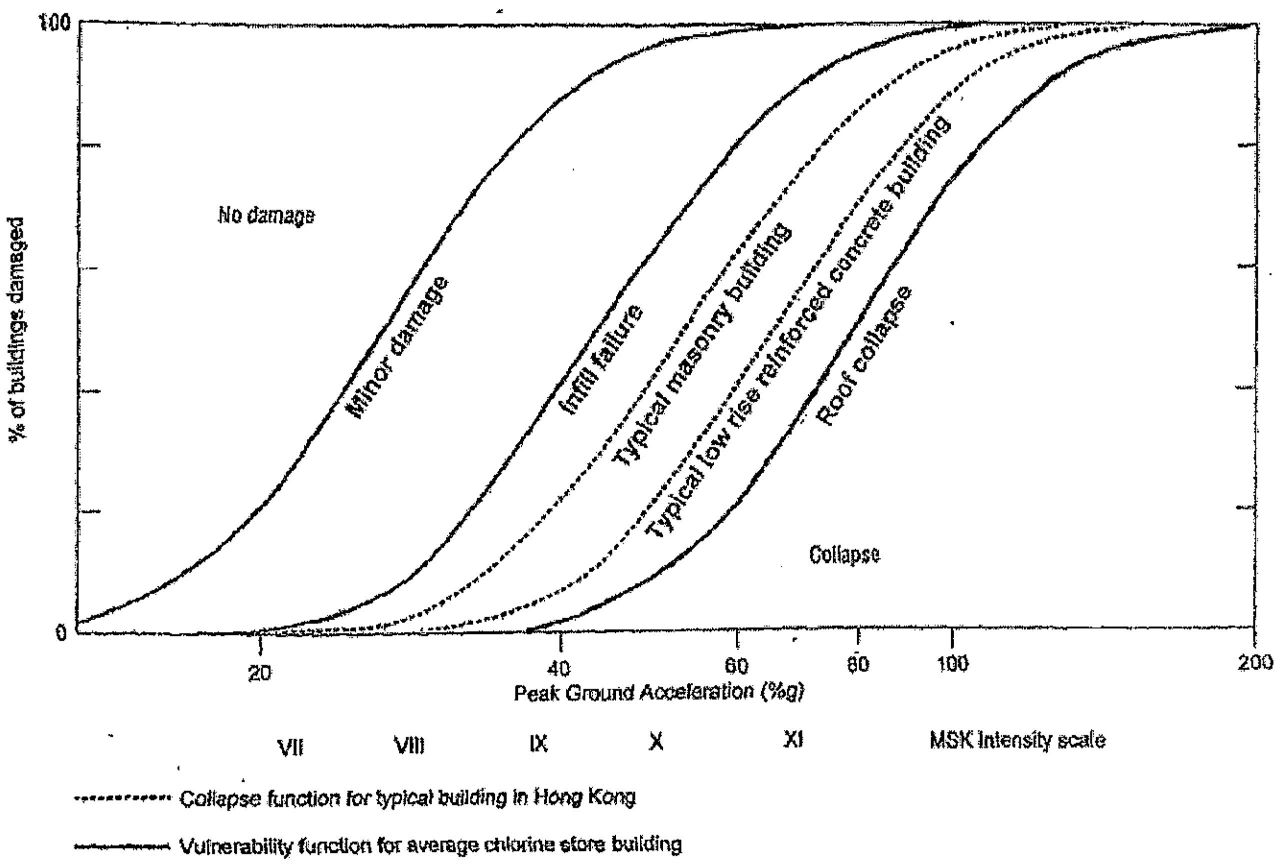

Figure G1 *Building Seismic Vulnerability*

Figure G2 *Event Tree for Seismic Hazards Assessment at Sheung Shui WTW*

					Outcome (Buildings near YKT WTW)		
Magnitude of earthquake	Frequency (per year) (Note 1)	Roof collapse ? (Note 2)	Number of containers failing (Note 3)	Frequency (per year)	Percentage of buildings damaged and associated level of damage (from *Figure 8.1* in Ove Arup, 1999) (Note 4)	Probability of fatality (Note 5)	Surviving percentage of population (Note 6)
0.5g	3.3E-06	Y (p = 0.1)	14	3.3E-07	20 % (collapse)	0.95	71%
					30 % (partial damage)	0.5	
		N	None				
0.8g	1.4E-07	Y (p = 0.5)	14	7.0E-08	70 % (collapse)	0.95	23%
					20 % (partial damage)	0.5	
		N	None				

Note 1: from *Daya Bay Risk Assessment* (Cook, et al, 1993)
Note 2: probabilities of roof collapse from Ove Arup (2000) (See Figure G2)
Note 3: number of drums failing and associated probability from Ove Arup (1999) but simplified to a single outcome
Note 4: reference curve in *Figure 8.1*of Ove Arup (2000) is that for typical low rise reinforced concrete buildings
Note 5: probability of fatality for total collapse of a building estimated to be 95% and for partial damage 50%
Note 6: % surviving population = 1 - [% of buildings collapsing x p(fatality due to collapse) + % of buildings partially damaged x p(fatality due to partial damage)]