Appendix 12.7

Seismic Hazard Assessment

A12.7-1 SEISMIC HAZARD ASSESSMENT

A12.7-1.1 INTRODUCTION

This Appendix presents a summary of the Seismic Hazard Assessment for the Eight WTWs Study which was undertaken by Ove Arup (2001). The following paragraphs summarise the work which has been undertaken and the application of the results of the Seismic Hazard Assessment in the QRA.

A12.7-1.2 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.

A12.7-1.3 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.

A12.7-1.4 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 (*Figure 1.1*);

- 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 (i.e. low rise buildings up to 10 storeys in height).
- there is no 'partial' failure mode of the chlorine buildings, i.e. 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, e.g. 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 300mm×500mm 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 Sha Tin WTW focuses on earthquakes which could cause roof collapse leading to multiple catastrophic failures of chlorine drums. Two magnitudes of earthquake are considered: 0.7g/MMXI (10% chance of roof collapse) and 1.0g/MMXII (50% chance of roof collapse) as shown in *Figure 1.1* (Ove Arup, 2001). The lower level of earthquake (0.4g/MMIX) which could cause the crane to come off its rails and split a drum is not considered significant because the release would be contained within the chlorine building (the infill walls at Sha Tin are of reinforced concrete construction).

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). Note that the earthquake-surviving fraction of the population of the elevated Hin Keng Station (population unit Z6) which, due to the open character of the station is considered in this QRA as basically outdoors, is estimated in the same way as indoor population of other buildings.

Figure 1.2 summarises the modelling of seismic hazards in the QRA for Sha Tin WTW in the form of an event tree showing the various outcomes of earthquakes of magnitude 0.7g (MMXI) and 1.0g (MMXII).

In *Figure 1.2* the 'surviving fraction of the indoor population' calculated in the last column is used to modify the population data (*Table 12.3* 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, i.e. through falling masonry.

A summary of the drum impact assessment for Shatin WTW is shown in *Table 1.1* below:

Table 1.1 Evaluation of the Damage to the Chlorine Containers for Collapse of Building Structures

Site Name	**Sha Tin**	
Minimum number of drums ruptured	35	(25)
Intermediate number of drums ruptured	40	(25)
Maximum number of drums ruptured	47	(50)
Weighted average	42	

Note 1: Likelihood (%) of effect

The number of drums ruptured in scenarios where the storage is reduced from 221 tonnes to a lower level is obtained by reducing 42 (number of drums ruptured for the case of 221 tonnes storage) in proportion to the reduced storage level. This is because the according to Ove Arup (2001) the roof beams do not necessarily fall on the drums in predicted ways, but may impact drums located anywhere within several m (the storey height, i.e. 5.5 m) from the original location of the beam. Since in case of the Sha Tin WTW chlorine store the distance between the drum racks and the drums themselves is lower than the storey height and the maximum roof beam displacement distance, it can be concluded that in a case of reduced storage no particular layout of the chlorine drums with regard to the roof beam location could reduce the probability of drum failure. Thus, the drum failure pattern is basically random, and the number of drum failures is proportional to the total number of drums in store seems reasonable. Note that results of a recent detailed seismic analysis for two storage levels in a CCPHI-approved Hazard Assessment for Tai Po WTW[1] have also shown that the number of drum failures in a roof collapse scenario is proportional to the assumed storage level.

[1] Expansion of Tai Po Water Treatment Works Investigation Study: Hazard Assessment, ERM Report to Black&Veatch, February 2009

Figure 1.1 *Building Seismic Vulnerability (Figure 8.1 of Ove Arup, 2001)*

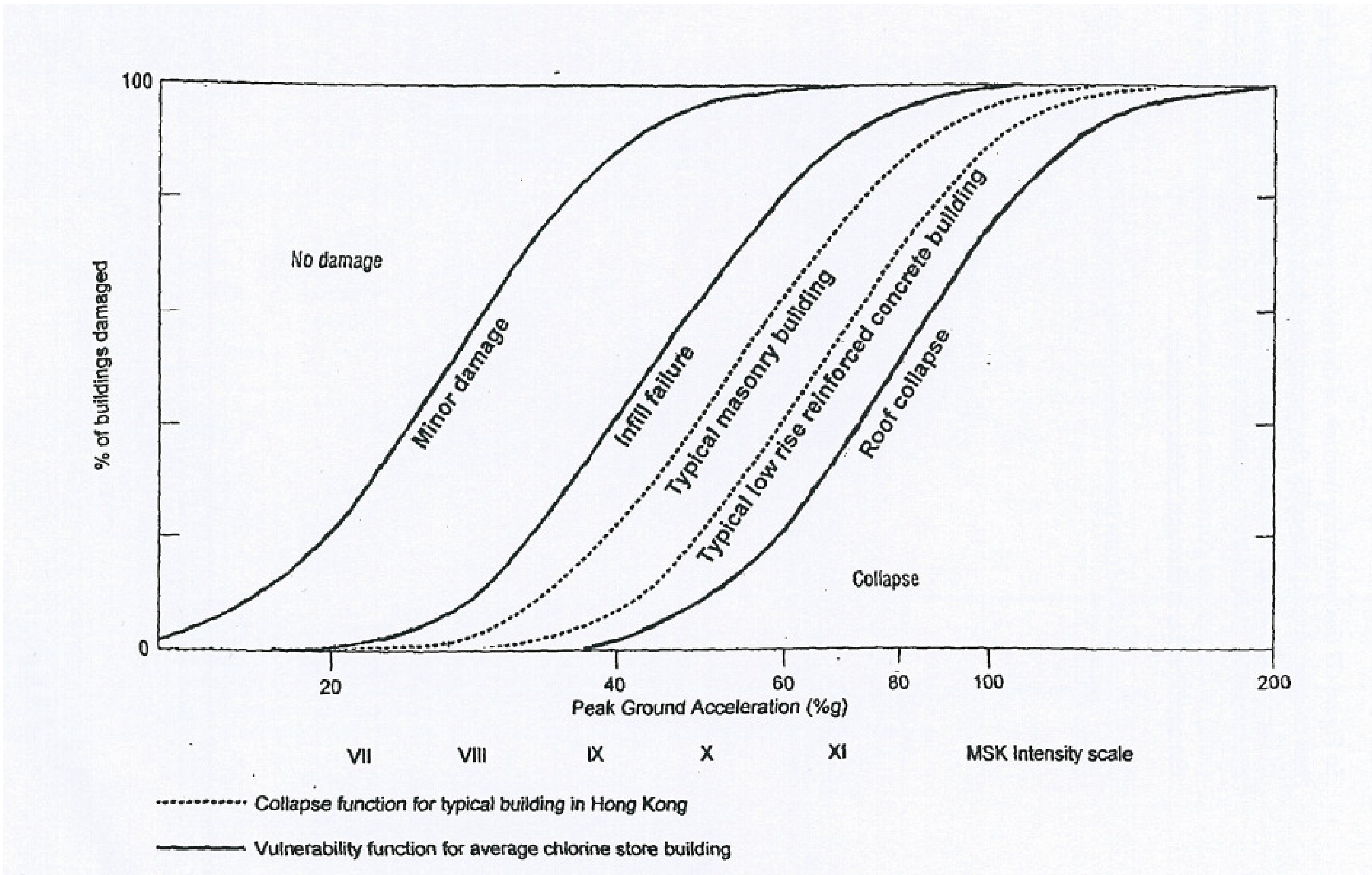

Figure 1.2 Event Tree for Assessment of Seismic Hazards (Sha Tin WTW)

Magnitude of earthquake	Frequency (per year) (Note 1)	Roof collapse ? (Note 2)	**Outcome (Chlorine store)** Number of containers failing (Note 3)	Probability (Note 3)	Frequency (per year)	**Outcome (Buildings near Sha Tin WTW)** Percentage of buildings damaged and associated level of damage (from *Figure 8.1* in Ove Arup, 2001) (Note 4)	Probability of fatality (Note 5)	Surviving percentage of population (Note 6)
0.7g	4.0E-07	Y (p = 0.1)	42	1.0	4.0E-08	60 % (collapse)	0.95	23%
						40 % (partial damage)	0.5	
		N	Not significant					
1.0g	2.5E-08	Y (p = 0.5)	42	1.0	1.3E-08	90 % (collapse)	0.95	10%
						10 % (partial damage)	0.5	
		N	Not significant					

Note 1: from *Daya Bay Risk Assessment* (Cook, et al, 1993)
Note 2: probabilities of roof collapse from Ove Arup (2001)
Note 3: number of drums failing and associated probability from Ove Arup (2001) but simplified to a single outcome with 42 drums failing
Note 4: reference curve in *Figure 8.1*of Ove Arup (2001) is that for typical low rise reinforced concrete buildings (i.e. up to 10 storeys), which is considered to represent average of buildings around Sha Tin WTW
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)]