Tunnelling and Underground Space Technology 43 (2014) 78–87

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Fire safety strategies for existing rock caverns in Hong Kong

T.K. Tam [a], H.L. Tsang [a], Gigi C.H. Lui [b], N.K. Fong [b], W.K. Chow [b,*]

[a] Fire Services Department, Hong Kong, China
[b] Research Centre for Fire Engineering, Department of Building Services Engineering, The Hong Kong Polytechnic University, Hong Kong, China

ARTICLE INFO

Article history:
Received 6 December 2012
Received in revised form 11 March 2014
Accepted 4 April 2014
Available online 15 May 2014

Keywords:
Cavern
Fire safety
Overview

ABSTRACT

Rock cavern development is not a brand new concept in Hong Kong. In accordance with the recommendations of various studies conducted in Hong Kong, the use of rock caverns with high occupant loads is not impossible. All the existing cavern projects in Hong Kong, however, were designed to have low occupant loads and used as public utilities such as sewage treatment works, explosives depot, refuse transfer station, salt water service reservoirs and explosives magazine complex. In order to determine the possibility of utilizing caverns, from fire safety perspective, for potential uses other than public utilities with low occupant loads, this paper aims to critically review the fire safety strategies of the existing rock caverns in Hong Kong. The results of radon level measured in the largest rock cavern in Hong Kong are also demonstrated to determine whether cavern in Hong Kong is suitable for public use in terms of indoor radon concentration according to the relevant standard suggested by the World Health Organization. Further, recommendations are offered to facilitate possible utilization of rock caverns with high occupant loads in Hong Kong such as introducing new fire safety strategies and updating fire safety provisions for the existing rock caverns.

1. Introduction

As proposed by the Chief Executive at his 2009–2010 Policy Address of the Government of the Hong Kong Special Administrative Region (HKSAR) (Government of the HKSAR, 2009), the Development Bureau of HKSAR put forward a new initiative to launch strategic planning and technical studies to facilitate planned development of underground space. This aimed at promoting the enhanced use of rock caverns as an attempt to pursue sustainable development. In fact, utilization of rock caverns was not a brand new concept in Hong Kong. In 1991, the use of underground space in rock caverns was recognized as a viable alternative to the conventional aboveground developments, and it could bring significant economic and environmental benefits to the society. Therefore, the HKSAR Government implemented policies to encourage cavern developments in suitable locations. To push forward the strategic planning initiative, the Government conducted the Study of the Potential Use of Underground Space (SPUN) (Ove Arup and Partners Ltd., 1990). Based on the findings of the SPUN study, Malone (1996), former Head of Geotechnical Engineering Office, summarized the catalogue of possible uses for rock cavern development in Hong Kong as in Table 1. As listed in the table, uses with high occupant loads with sleeping risks including residential, hotel, education and hospital/polyclinic/clinic, etc., were classified as 'unsuitable' (Malone, 1996). However, other potential uses with high occupant loads in nature such as civic centre/community centre, indoor games/sports hall, market (wholesale and retails), as well as transport connections and networks, were categorized as 'possible' for rock cavern developments. It was also recommended that the utilization of rock caverns with high occupant loads was possible.

Following the findings and recommendations of SPUN, administrative guidelines on the planning of cavern use are also provided in Chapter 12 of the Hong Kong Planning Standards and Guidelines (HKPSG) by the Planning Department (2008). A list of potential land uses for the existing caverns is included and the potential uses with high occupant loads such as civic centre, indoor games/sports hall, wholesale market as well as transport connections and networks are also presented, as shown in Table 2. According to the latest feasibility study the "Enhanced Use of Underground Space in Hong Kong" (Ove Arup and Partners Ltd., 2011) commissioned by the Civil Engineering and Development Department (CEDD), a number of government facilities which could also be considered for replacement or reprovisioning in rock caverns were identified. For instance, the kinds of facilities that someone objects

* Corresponding author. Address: Department of Building Services Engineering, The Hong Kong Polytechnic University, Hunghom, Kowloon, Hong Kong, China. Tel.: +86 (852) 2766 5843; fax: +86 (852) 2765 7198.
E-mail addresses: beelize@polyu.edu.hk, bewkchow@polyu.edu.hk (W.K. Chow).

http://dx.doi.org/10.1016/j.tust.2014.04.001
0886-7798/

Table 1
Possible uses for rock cavern development (Malone, 1996).

	Land use	Possible	Unsuitable
1.	Residential (including residential institution)		•
2.	Commercial		
	Office	•	
	Retail	•	
	Entertainment	•	
	Hotel		•
	Ancillary parking	•	
3.	Commercial/Residential		
	Commercial elements	•	
	Residential elements		•
4.	Industrial		
	Industry	•	
	Storage/warehousing	•	
	Oil bulk storage	•	
	Liquefied Petroleum Gas (LPG) bulk storage	•	
5.	Education		•
6.	Vehicle Parking	•	
7.	Open Space		•
8.	Government/Institution/Community		
	Abattoir	•	
	Civic centre/community centre	•	
	Hospital/polyclinic/clinic		•
	Incinerator	•	
	Indoor games/sports hall	•	
	Market (wholesale and retails)	•	
	Refuse transfer facilities	•	
	Sewage/water treatment	•	
	Service reservoir	•	
	Transport connections and networks	•	
	Cemetery/crematorium		•
	Columbarium/mausoleum/mortuary	•	
9.	Utilities		
	Power stations/electricity sub-stations	•	

Table 2
Potential land uses for rock cavern development.

Land use category	Potential land uses in the current HKPSG (Planning Department, 2008)	Potential land uses proposed to be added to HKPSG (Chan, 2011; Ove Arup and Partners Ltd., 2011)
Commercial	Retail	Food/wine storage Warehousing
Industrial	Industry LPG bulk storage Storage/warehousing	Dangerous goods Data centre Research laboratories Science park
Government, Institution & Community (GIC)	Civic centre Columbarium/ mausoleum/ Mortuary Incinerator Indoor games/sports hall Refuse transfer facility Sewage/water treatment plant Service reservoir Slaughterhouse Transport connections & networks Wholesale market	Archives Bicycle park-and-ride Car/vehicle parking Crematorium Refuse collection point Maintenance depot for rail Underground quarrying
Public Utilities	Power station	Substation

to be sited in their own neighborhood but does not object to it being sited elsewhere are typically more suitable to this type of transfer, especially those located near urban or urban fringe areas.

The types of land uses that have a high preference for cavern development are also listed in Table 2 (Chan, 2011; Ove Arup and Partners Ltd., 2011). In accordance with the findings, potential land uses with high occupant loads such as science park were also proposed. Existing rock caverns in Hong Kong, however, mainly accommodate public utilities with low occupant loads, such as sewage treatment works, explosives depot, refuse transfer station, salt water service reservoirs and explosives magazine complex.

Notwithstanding that no big fire has happened in rock caverns so far, the inherent fire risks inside rock caverns are very similar to other enclosed spaces such as underground spaces. Fire physics in enclosed spaces has yet to be clearly understood as well. In case of an internal fire or explosion happen in an underground structure, the impact in terms of internal damage and personnel risk (Sterling and Nelson, 2013) is normally greater than those occur in a surface structure (Sterling et al., 2012). In this regard, fire safety in rock cavern is a paramount factor for determining whether such cavern is suitable to accommodate high occupant loads or not. Owing to the unique and complex design nature of rock caverns, performance-based fire safety designs have been widely adopted in the planning of rock cavern projects around the globe. In terms of the formulation of fire safety provisions for the existing rock caverns in Hong Kong, they were mainly based on fire engineering approach with performance-based design and such provisions are tailor-made for each cavern according to its size as well as usage. Thus, no prescriptive fire safety requirement is available for rock cavern development in Hong Kong. The fire safety designs of various caverns in Hong Kong are therefore worth studying to identify the general fire safety issues of rock caverns from the technical perspective. In this respect, this paper aims to critically review the fire safety strategies in terms of means of access, means of escape, ventilating and smoke control system, fire service installations and fire safety management of existing rock caverns in Hong Kong so as to identify the general fire safety issues of rock caverns. Further, from fire safety point of view, this paper intends to determine the possibility of utilizing caverns in Hong Kong other than public utilities with low occupant loads by making reference to the fire safety provisions for existing rock caverns. Relevant recommendations on further research work such as introducing new fire safety principles strategies, updating fire safety provisions for existing rock caverns as well as conducting further studies in relation to fire safety issues in caverns are also offered.

2. General function, layout, means of access and means of escape of the existing cavern developments in Hong Kong

In the mid-1990s, a few purpose-built rock caverns were constructed in Hong Kong to accommodate government facilities such as sewage treatment works, explosives depot, refuse transfer station, salt water service reservoirs and explosives magazine complex to meet the needs of the community for optimizing the land use in underground space. The general functions, layouts, means of access (MoA) and means of escape (MoE) of the cavern projects are outlined as follows:-

2.1. Sewage treatment works

The first rock cavern project in Stanley, which was built in November 1990 and commissioned in February 1995, was utilized as sewage treatment works. The treatment plant was constructed inside three caverns, each with a size of about 30,600 m^3 (about 120 m long, 15 m wide and 17 m high) (Ip and Sam, 2011). The plant is currently serving a population over 27,000 with a design capacity of 11,600 m^3 per day. Fig. 1 shows the entrance of the sewage treatment works.

The treatment plant is a 450 m-long tunnel-like structure with a 177 m-long, 6.5 m-high main access tunnel and ventilation shafts. The main access tunnel slopes downwards serving also as