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Assessment and planning of underground space use in Singapore

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ABSTRACT

Underground space development has become an economic imperative for land-scarce Singapore. In 2007, the government, under the Ministry of National Development, set up an inter-agency Underground Master Planning Task Force that aims to map out the long-term development of the underground space, bringing the underground space development to a strategic level. In 2010, the Economic Strategies Committee made developing underground space part of the government's long-term economic strategy with specific recommendations on master planning, geological investigations, investment in research and development, and various policy issues. The ESC report also recommended that the government should take the lead in catalysing the use of underground space. Based on these recommendations, the Singapore government have taken various initiatives and studies, and initiated various research projects in support of these initiatives.

This paper gives a review of the history of underground space development, highlights the potential utilisations, and discusses the various recent studies and planning issues, and examines possible strategies for future use of underground space in Singapore.

1. Introduction

Singapore consists of one larger and several smaller islands, and lies at the southern end of the Malay Peninsula with a roughly diamond shaped area between latitude 1°09′N and 1°28′N and longitude 103°38′E and 104°06′E. With a high population density and continually developing economy, Singapore faces a severe lack of land space for development. The increasing population, coupled with the government plan for more green space for the population, means more competition for land. Table 1 shows the change of land use distribution in Singapore from 1960 to 2007 (Malone-Lee, 2011).

Land has always been recognised as a constraint by the Singapore government. According to the Department of Statics of the Singapore government, the population in 2013 was 5.5 million. With a total land area of 716.1 km^2, the population density stood at 7540 persons/km^2. This compares to a population density of 42,852 persons/km^2 in Manila and 21,498 in Paris (Wikipedia, 2015). In fact, the population density of Singapore is not even in the top 50 cities in the world. However, what makes it unique and more challenging for Singapore is that Singapore is also a country. To put it in perspective, Singapore would rank 2nd in terms of population density per country after Monaco. Singapore must address both the needs of a modern metropolis as well as the need of a country. The development of the underground ammunition facility by the Ministry of Defence was case in point. No cities in the world have to store ammunitions in their urban area. In fact, most cities do not have to cater for defence requirements in such large proportions as Singapore. The storage of ammunition near the population not only places severe constraints on land use, it also places great demand on safety. This is the reason why underground ammunition storage in Singapore has so much advantage compared to other countries.

The land squeeze is expected to get worse according to planning numbers published by the government. According to the land use plan of the government published in 2013, the expected land use will be 766 km^2 by 2030 when the population is expected to increase to between 6.5 and 6.9 million from the current 5.5 million (National Population and Talent Division, 2013), a net increase of land requirement of about 50 km^2 from 716 km^2 in 2013. Even if the 50 km^2 increase in land space can be achieved, this would only represent a 7% increase, compared to the population increase of between 18% and 25% based on the above numbers (Table 3). Clearly, the pressure on land will only increase.

From Table 2, it can be seen that the largest land users are Defence (19%), Housing (17%), Industry and Commerce (17%), and land transport infrastructure (13%), accounting for 66% of the total

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Table 1
Land use distribution in Singapore 1960–2000 (Malone-Lee, 2011).

Year	Land area, km^2	Build-up, km^2	Agriculture, km^2	Forest, km^2	Marsh & tidal waste, km^2	Others (water, open space, gardens, cemeteries), km^2
1960	581.4	162.3	141.7	37.8	45.9	193.8
1965	581.4	177.4	131.6	35.0	35.0	202.5
1970	586.4	189.9	134.0	32.4	32.4	197.7
1975	596.8	228.4	105.9	32.4	32.4	197.7
1980	617.8	275.1	80.9	30.0	26.0	205.8
1985	620.2	298.8	47.1	28.6	18.5	227.5
1990	639.1	311.6	10.8	28.6	15.7	266.4
1995	647.5	319.3	9.3	28.6	15.7	274.6
2000	682.7	324.0	9.3	28.6	15.7	274.6
2012 Estimate	714.3	418.4	9.3	28.6	15.7	238.2

Table 2
Land use plan for 2010 and 2030 (URA, 2013).

Land use	Planned land supply	
	2010	2030
Housing	10,000 (14%)	13,000 (17%)
Industry and commerce	9700 (13%)	12,800 (17%)
Parks and nature reserves	5700 (8%)	7250 (9%)
Community, institution and recreation facilities	5400 (8%)	5500 (7%)
Utilities (e.g., power, water treatment plants)	1850 (3%)	2600 (3%)
Reservoirs	3700 (5%)	3700 (5%)
Land transport infrastructure	8300 (12%)	9700 (13%)
Ports and airports	2200 (3%)	4400 (6%)
Defence requirements	13,300 (19%)	14,800 (19%)
Others	10,000 (14%)	2800 (4%)
Total	71,000 (100%)	76,600 (100%)

Table 3
A comparison of population and land use (URA, 2013).

Land and population	Year 2014	Year 2030	Change
Land size	716 km^2	766 km^2	50 km^2 (7%)
Population	5.5 mil	6.5–6.9 mil	1–1.4 mil (18–25%)

land. After this group, parks and nature reserve take up 9%, a reflection of the country's drive to keep her reputation as a garden city. It is also significant to note that the amount of reserve land has been reduced from 14% in 2010 to 4% in 2030, leaving relatively little reserve for further allocation after 2030 (Table 3).

Traditionally, Singapore has tackled the land constraints with high-rise buildings and land reclamation. In fact, more than 20% of the present land area has been created by filling up the sea (Fig. 1). From her independence in 1965–2014, Singapore's land size grew by 22% by land reclamation (The Economist, 2015). However, land reclamation is reaching its limits due to geographical boundaries, increasing water depths, the increasing cost of sand supply and environmental concerns. For high-rise buildings, Singapore also faces additional constraints due to civil aviation and defence needs primarily due to the small size of the country, problems most other urban areas do not have.

2. Geology of Singapore

Singapore is of moderately low relief. Most of land areas range 10–30 m in elevations. The area of highest relief is at the Northern Central of Singapore, the Bukit Timah area, where the highest hill rises to 163 m above mean sea level. In regional geology, Singapore is of a southerly projection of the Geology of the Malay Peninsula, which is the south-eastern extremity of the Eurasian tectonic plate.

2.1. Main geological formations

The Singapore rocks consist mainly of, in order of geologic age from old to young, four geologic formations (DSTA, 2009): (1) Bukit Timah granite, (2) Sajahat Formation of metamorphic quartz sandstone and mudstone, (3) Gombak norite, and (4) Jurong Formation sedimentary rocks.

The Bukit Timah granite (BT) forms the major basement rock of Singapore and covers about one-third of the Singapore island, with distribution at central main island, Pulau Ubin island, and the surrounding sea area. The term granite is used in a general sense for the entire suite of acid rocks including granite, adamellite, granodiorite, and the acid and intermediate hybrids (mainly of granodioritic and dioritic composition) which resulted from the assimilation of basic rock within the granite.

The Sajahat Formation (S) is probably the eldest rock formation in Singapore. It is variably metamorphosed sedimentary rocks comprising quartzite, sandstones, and argillite. The Sajahat Formation (S) mainly distributes at Pulau Sajahat, Sajahat Kechilkong, along north coast of Pulau Tekong and as far to the east as Tanjong Renggam.

The Gombak Norite (GN) is a body of noritic and gabbroic rock with exposure on the western side of the Bukit Timah Granite on Singapore Island. The unit is named after Bukit Gombak where noritic and gabbroic rocks are well exposed in a number of quarries. The noritic and gabbroic rocks are coarse-grained and plagioclase-rich with varying amounts of clino- and orthopyroxene minerals appearing as interstitial grains giving an intergranular texture to the rock.

The Jurong Formation (JF) sedimentary rock is the youngest rock formation in Singapore. It overlies the above basement rock formations, and extensively covers one-third of the main island area of Singapore. It distributes at south and southwest Singapore. Extensive areas in the Jurong Formation have been affected by dynamic metamorphism resulting from tectonic activity. The grade of metamorphism is low, and it is still possible to determine the facies that has been affected.

Overlying the above basement rocks, shallow overburden deposits include residual soils, the Kallang Formation, the Fort Canning Boulder and the Old Alluvium. The Old Alluvium Formation is dominantly terrestrial deposit of early Pleistocene age and distributes at eastern part of Singapore, occupying one-third of Singapore main island area. It comprises mainly medium dense to very dense, semi-indurated, and clayey quartzo-feldspathic coarse sand and fine gravels.

The Kallang Formation includes both marine and terrestrial sediments laid down from late Pleistocene to the present day. These deposits cover much of the coastal plain, immediate offshore zone and the deeply incised river valleys. The Marine Sedimentary Unit is found in the eastern part of Singapore. It occurs over an area covering one quarter of Singapore Island.

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