CAVERN AREA STUDY
OF
KOWLOON

GEO REPORT No. 101

K.J. Roberts & P.A. Kirk

GEOTECHNICAL ENGINEERING OFFICE

CIVIL ENGINEERING DEPARTMENT

THE GOVERNMENT OF THE HONG KONG

SPECIAL ADMINISTRATIVE REGION

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Geotechnical Engineering Office,
Civil Engineering Department,
Civil Engineering Building,
101 Princess Margaret Road,
Homantin, Kowloon,
Hong Kong.

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PREFACE

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. A charge is made to cover the cost of printing.

The Geotechnical Engineering Office also publishes guidance documents as GEO Publications. These publications and the GEO Reports may be obtained from the Government's Information Services Department. Information on how to purchase these documents is given on the last page of this report.

R.K.S. Chan
Head, Geotechnical Engineering Office
April 2000

FOREWORD

Chapter 11 of the Hong Kong Planning Standards and Guidelines includes Guidelines for Underground Rock Cavern Development. Since the introduction of these guidelines, which were endorsed by LDPC in September 1991, three Cavern Area Studies have been completed for the North Lantau Area (1992), Hong Kong Island West (1993) and Hong Kong Island East (1994).

This Cavern Area Study covers the Kowloon urban area. It differs from previous studies in that the maps are computer generated. Much of the required input data are now available in digital format, and have been incorporated into a Geographic Information System (GIS) and manipulated by means of simple queries to form a Cavern Area Study Map.

The study was carried out by Mr K.J. Roberts (GE/A1) and Mr P.A. Kirk (GE/GS). The report drawings and maps were produced by Mr Y.M. Tam (TO/CARTO) under the supervision of Ms P.L. Chan (STO/CARTO).

H. Choy

(H. H. CHOY)
Atg Chief Geotechnical Engineer/Planning

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1. INTRODUCTION

This report considers the potential of the terrain in the Kowloon urban area (Figure 1) for the development of underground space using man-made rock caverns. Caverns are used in many parts of the world to accommodate new developments, and to enable growth of existing developed areas (Subspace Associates, 1990), particularly those where terrain conditions are difficult for above-ground development. Summaries of experience in rock cavern applications are given by Hoek and Brown (1982), Sharp (1989), Ove Arup & Partners (1989a) and GEO (1992).

In early 1988, the Hong Kong Government initiated the SPUN Study (SPace UNderground) to investigate the feasibility of excavating rock caverns in Hong Kong (Pryor, 1989). This was undertaken as part of the Planning Department’s Metroplan Study. In December 1989 an international symposium on the applications of man-made rock caverns was held in Hong Kong, with emphasis on land planning (Malone & Whiteside, 1989). In July 1990 the Planning Department established a “Working Group on Development Guidelines for Underground Rock Caverns” and the final guidelines were endorsed by LDPC in September 1991 and have been included in Chapter 11 of the Hong Kong Planning Standards and Guidelines (Appendix A).

The main purpose of a Cavern Area Study (CAS) is to classify the suitability of land for rock cavern development based predominantly on general engineering geological information. A CAS is the first of a number of steps in the planning process suggested by the Working Group on Development Guidelines for Underground Rock Caverns as shown in Figure 2. Once a possible use is identified by town planners using the CAS Map, the Geotechnical Engineering Office will carry out a Preliminary Engineering Geology Study (PEGS) to better define a suitable cavern location, propose alternative access arrangements and to estimate the likely cost of cavern construction. Details of CAS and PEGS are given in Roberts et al, (1997).

The first Cavern Area Study was completed in August 1992 for the North Lantau Area (Choy & Styles, 1992). Subsequent studies for Hong Kong Island (Roberts, 1993, 1994) arose from the initiatives created by the SPUN Study and recognition of the potential benefits of underground space in the Development Statement for the Central - Western Districts (Planning Department, 1992).

This report is based on information from the following sources:

(a) Allen and Stephens: Report and Map of the Geological Survey of Hong Kong (Allen and Stephens, 1971).

(b) Hong Kong Geological Survey: Geological Map, Hong Kong and Kowloon, Sheet 11, 1:20 000. Solid and Superficial Geology (GCO, 1986a).

(c) Hong Kong Geological Survey: Geological Map, Sha Tin, Sheet 7, 1:20 000. Solid and Superficial Geology (GCO, 1986b).

(d) Hong Kong Geological Survey: Geological Map Sheets 11-NW-A, 11-NW-B, 11-NW-C, 11-NW-D & 11-NE-C, 1:5 000. Solid Geology (GEO, 1996).

(e) Geotechnical Control Office: Geology of Hong Kong Island and Kowloon, Memoir No. 2 (Strange & Shaw, 1986).

(f) Geotechnical Control Office: GASP Report I, Hong Kong and Kowloon (GCO, 1987).

(g) Geotechnical Engineering Office: Geoguide 4: Guide to Cavern Engineering (GEO, 1992).

(h) Ove Arup & Partners (1989a): SPUN - Cavern Engineering Report.

2. THE STUDY AREA

2.1 General Description

The study area covers the Kowloon urban area (Figure 1) with its northern boundary being located within the foothills of Beacon Hill, Lion Rock and Tate's Cairn, generally extending west to east from Lai Chi Kok to beyond Tsz Wan Shan. From Tsz Wan Shan the study boundary is generally south to southeast trending from Tate's Cairn through Kowloon Peak and towards Yau Tong Bay. For simplicity, the limits of the study follow the boundaries of a number of Outline Zoning Plans (OZP's). The total area is approximately 43.8 km^2.

The area of Kowloon is densely populated. Urban development in the study area is constrained inland by steep terrain culminating in a hill chain extending eastwards from Beacon Hill (452 m) to Lion Rock (494 m), Tate's Cairn (577 m) and Kowloon Peak (602 m). The coastal areas from Kwun Tong in the east to Kwai Chung in the west have been extensively reclaimed.

Information on the general characteristics of the terrain in the study area is provided in GASP Report I on Hong Kong and Kowloon (GCO, 1987).

2.2 Solid Geology

The first systematic geological mapping was carried out by Allen and Stephens (1971) at a scale of 1:50 000. The area is covered by Sheet 11 (GCO 1986a) and Sheet 7 (GCO, 1986b) of the 1:20 000 scale, solid and superficial geology map series prepared by the Hong Kong Geological Survey (HKGS) of the Geotechnical Engineering Office. The geology is described in the associated geological memoir for Hong Kong and Kowloon (Strange and Shaw 1986). Recent detailed mapping of the solid geology has also been completed at a scale of 1:5 000 (GEO, 1996) for parts of the study area.

The study area is almost entirely underlain by granite of the Kowloon Pluton (named by Strange, 1990). The Kowloon Pluton crops out in an almost circular area, about 10 km diameter, that extends from Lion Rock in the north of the Kowloon Peninsula to Wong Nei Chung Gap on Hong Kong Island, and from Stonecutters' Island in the west to Lei Yue Mun in the east. The study area coincides with much of the northern part of the pluton.

The Kowloon granite is typically medium or fine-medium grained, and equigranular. Much of the area is characterised by lithological uniformity, and this is one of the key reasons that the area provides a predictable and usually favourable substrate for engineering works.

Some textural variation does exist, for example, megacrystic fine-grained granite occurs in the King's Park area of Kowloon Peninsula. More significant for engineering however, is the alteration or mineralisation that has been noted, locally, near the margins of the pluton. Mineralisation is best developed in the east (Lei Yue Mun to Rennie's Mill) and clay-rich altered zones have been encountered elsewhere at Stonecutters' Island and at Central on Hong Kong Island. The most highly altered lithology has been worked as a kaolin mine at Cha Kwo Ling, East Kowloon, (Strange and Shaw, 1986).

The Kowloon Pluton is one of the youngest intrusive rocks in Hong Kong, and is therefore little affected by later intrusions. Basalt dykes do intrude the granite however, and these are not uncommon in the east of the study area.

Only a few very small areas within the study area are not underlain by Kowloon Granite. At the northwest edge of the study area, a narrow strip is underlain by coarse-grained granite of the Sha Tin Pluton. In the east there are several small areas underlain by volcanic rocks of the Repulse Bay Volcanic Group. These occur on the high ground northwest of Kowloon Peak, and around Tai Sheung Tok. Lithologies are fine- or coarse-ash tuffs.

The regional geological lineaments and fault systems, and their proposed classification, have been described by Burnett and Lai (1985). The distribution of known faults is shown on Drawing No. EG 498. Two sets of faults are present, one trending NE-SW and the other NW-SE, although there is some range of trend directions. The faults are usually steeply-dipping (65 degrees or steeper), but shallower dipping structures have been described. Faults are often concealed beneath superficial deposits, so descriptions of the materials at faults are not common. "Typical" faults in this area probably have a crush or shear zone from one metre up to several metres thick. However, one fault may comprise several such zones, and the zone affected by intense jointing is likely to be thicker up to tens of metres thick. Alteration by hydrothermal processes and weathering occur preferentially in fault zones. Valley systems and zones of deep weathering are commonly collinear with faults (Strange and Shaw, 1986; Shaw, 1997).

2.3 Photogeology

A number of photolineaments have been previously defined in the study area particularly in GASP Report I (GCO, 1987b). This information was supplemented with aerial photographic interpretation to examine the lineaments in more detail.

A lineament is a significant line in the landscape which reflects the underlying solid rock structure. These features show up well on aerial photographs and are known as geological photolineaments when viewed in three dimensions using a stereoscope.

Prominent geological photolineaments are usually the surface expression of major faults, but they can also result from the presence of zones of intense jointing, veins, dykes, or sills in Hong Kong (Burnett & Lai, 1985). Photolineaments that coincide with inferred or actual faults indicated by the Hong Kong Geological Survey mapping at 1:5 000 scale are represented as faults on Drawing No. EG 498. The photolineaments and faults identified have dominant trends in a NE-SW and NW-SE direction.

At this stage of the study little is known about the extent of these faults and photolineaments with depth. To take account of a possible variation in dip angle with depth, as well as the possibility for zones of increased jointing and weathering in the vicinity of these features, all faults are assigned a buffer zone of 50 m either side of their mapped surface expression. Detailed site investigation will be required to locate these features at cavern depth once specific cavern locations have been established during the subsequent PEGS studies (Figure 2). Where photolineaments have not been confirmed as faults by the HKGS, a buffer zone is not considered necessary. However, the photolineaments are still shown on Drawing No. EG 498 and, if found to be present in an area identified as being suitable for cavern development, further investigation of these features is recommended in subsequent studies.

This study is for strategic planning purposes. The absence of any faulting or photolineament on Drawing No. EG 498 does not necessarily mean that potentially adverse conditions are not present. Any proposal for development, for caverns or other purposes, would require further, more detailed, site investigation.

3. THE CAVERN AREA STUDY (CAS) MAP

3.1 Introduction

The basic information considered in the preparation of the Cavern Area Study (CAS) Map are:

(a) existing and proposed surface developments,

(b) existing and proposed underground installations,

(c) engineering geological conditions, and

(d) topographic constraints.

Table 1 defines the land classes used in this study. These are slight amendments of the classes used for the Cavern Area Studies for North Lantau (Choy & Styles, 1992) and Hong Kong Island (Roberts 1993,1994) mainly because of the extensive surface development existing in this area and the detailed geological mapping available at 1:5 000 scale (GEO, 1996).

3.2 Existing and Proposed Surface Developments

As previously mentioned in Section 2.1 large parts of the study area are densely populated. In the early development stages of the CAS concept it was decided that cavern development would be preferred in areas where land ownership would not become a major issue. It was agreed with the Planning Department of the Hong Kong Government that the Outline Zoning Plans would provide the initial basis for evaluating suitable cavern sites (memo GCP 4/1C/86 dated 16.3.93 refers). Based on the Outline Zoning Plans, cavern development would be preferred beneath areas designated as GB (Green Belt), G/IC (Government/ Institution/ Community) or O (Open Space) to avoid possible future complications arising from land ownership and land resumption issues, in addition to the possibly more difficult engineering techniques required. Due to intensive development in some parts of Kowloon, large areas can therefore be considered as having low potential for cavern sites due to proximity of overlying developments and these are indicated in Drawing No. EG 498. The suitability of this class of land could be higher if the procedures for resumption of underground stratum beneath above-ground private development are simplified.

The locations of both fresh and salt water service reservoirs are indicated on Drawing No. EG 498. Although these structures are located on government land, they could impose restrictions on cavern development particularly due to limits placed on vibrations (peak particle velocities, PPV) which are developed during blasting. Caverns could be developed below or in the vicinity of such structures but would require strict monitoring and controls to ensure that the PPV’s do not exceed the 13 mm/s limit imposed for the reservoir structure. Such issues would need to be addressed in the more detailed PEGS study.

3.3 Existing and Proposed Underground Installations

An important aspect in planning subsurface space is identification of existing and proposed future underground installations such as tunnels or caverns (Gronfors, 1990). In Kowloon, many underground tunnels exist (Vail, 1989), and most of these are well-documented. Their general locations are shown on Drawing No. EG 498. Underground installations should be surrounded by a protective zone and any work which may threaten the safety of these underground installations should not be carried out within this zone. The extent of the protective zone should be determined from consideration of several factors including the thickness of the rock cover, engineering geological conditions, maximum span of the cavern, and the required safety standard. For example in Stockholm, once a protection zone is determined for an underground installation, a risk zone is further imposed by expanding the boundary of the protection zone by 50 m. Engineering works such as excavation, sheet piling or pile driving and drilling/blasting within the risk zone require prior approval (Jansson & Winquist, 1977).

Variable protection limits have already been established for the existing tunnels. However, for simplification, a protective zone of 50 m extending from the centre line of the existing underground installations is adopted for the purpose of this study as shown on Drawing No. EG 498. Existing underground installations include road tunnels such as the Lion Rock, Junk Bay and Tate’s Cairn tunnels, the Mass Transit Railway (MTR) and Kowloon-Canton Railway Corporation (KCRC) tunnels and the Strategic Sewage Disposal

Scheme (SSDS) tunnels and associated excavations. Land within the protective zones is classified as Cavern Land Class IIB (see Table 1). This class of land is considered of medium suitability for cavern development as it would probably require more detailed site investigation compared with Land Class I (as defined in Table 1), coupled with possibly higher excavation costs due to restrictions imposed on excavation techniques such as blasting in order to protect the existing underground installations from possible damage.

There are a number of proposed tunnel schemes in the study area including the Kowloon-Canton Railway Corporations West Rail Project, the Central Kowloon Route and possible MTR and KCRC extensions. For the purpose of this study it is only possible to include projects which have been Gazetted and subsequently approved for construction, and none of the aforementioned projects had reached this stage at the time of completion of this report. Finally, the alignment of the Airport Railway has not been shown as this is located entirely on reclamation within the study area.

3.4 Engineering Geological Conditions

The importance of engineering geological information in underground planning has been widely recognised (Stephansson, 1990; Jansson & Winquist, 1977). For example, in Finland, the country is divided into five separate regions on the basis of different rock quality for underground construction (FTA, 1988). Whilst it is possible to build caverns almost anywhere in rock with the use of appropriate construction techniques, development costs will increase substantially as the engineering geological conditions of the site become more difficult. Once suitable CAS areas have been identified a more detailed PEGS study should attempt to locate underground developments in areas which are favourable from an engineering geological point of view (Figure 2). However, this may not always be possible due to the complicated nature of issues relating to the cavern scheme such as locational constraints, access requirements and traffic etc.

The major engineering geological factors in planning underground development are quality of the rock mass, the existing stress regime and hydrogeology. Since rock mass properties are naturally variable, it is only practical to classify the rock mass into groups of broadly similar properties from the view point of rock construction techniques. Amongst these rock mass classification systems, the more popular methods are the NGI Tunnelling Quality Index (Barton, 1974; Hoek and Brown, 1982) and RMR classification (Bieniawski, 1974; Hoek and Brown, 1982). Barton (1989) considered Hong Kong's granites and welded tuffs to have Q Index values generally in the range of 7 to 20. This indicates that these rocks are generally of good quality for underground excavation. Barton stated that caverns of 20 m to 30 m spans have been successfully excavated and safely utilized elsewhere in rock masses of similar quality.

In the study area, the solid geology is dominated by granitic rocks. Where these rocks are fresh to slightly decomposed they are assumed to have Q values in the range of 7 to 20, i.e. similar to other Hong Kong granites classified by Barton (1989). While these fresh to slightly decomposed rocks are generally suitable for the excavation of rock caverns, the construction of caverns within major fault zones should be avoided, as these zones are often more weathered, mylonitised, crushed, sheared, altered or closely-jointed, and would have significantly lower Q values.

Based on the 1:5 000 Scale HKGS Mapping (GEO, 1996), a number of faults in the study area have a northeast or northwest trend. Shaw (1997) concluded that contouring of the weathering front in urban Kowloon, has demonstrated a strong correlation between its topography and both the main NE-SW trending and subordinate NW-SE structures. A clear relationship between topographical lows in the weathering front (bedrock) and the main faults and photolineaments was found. For planning purposes, the terrain within 50 m of a fault is classified as Cavern Land Class IIA as shown in Drawing No. EG 498**.**

As Cavern Land Class IIA terrain is likely to be influenced by possible major geological defects, the suitability for cavern development is less favourable than Class I due to the more extensive site investigation required to identify the exact location, extent and properties of these potential weakness zones. In addition, higher construction costs are also anticipated for caverns which are sited across faults although the effects of these features may be limited by careful orientation of the cavern. While the terrain near photolineaments is not included in Class IIA, these features would need to be more closely examined during later feasibility studies (PEGS) and design stages of the cavern development. These stages are described on the flow chart at Figure 2.

3.5 Topography

The construction of rock caverns is generally not constrained by topographically difficult terrain, such as the steep hillsides at Lion Rock or Tate's Cairn. The basic cavern design should ensure that the caverns are located sufficiently deep to leave a reasonable layer of unweathered rock above the cavern roof. Geoguide 4 (GEO, 1992) suggests that as a general rule the minimum cover of strong rock should not be less than half the cavern span and that in feasibility studies, based on limited information, it is prudent to assume a cover of strong rock of not less than the cavern span. For this study it is assumed that caverns will have a maximum span of 20 m (height or width) which will require 20 m of strong rock above the cavern roof. Shaw (1997) states that weathering profiles 10-20 m thick (to bedrock), occur over the Kowloon Peninsula, but thicken to about 40 m over hills and subsurface basins in the weathering front. Allowing for general depths of weathering below surface of up to 20 m, then a total cover of 40 m above the cavern roof is therefore assumed.

The Cavern Land Class I areas (as defined in Table 1), are subdivided into two categories, Class IA and Class IB according to the topography. If a 20 m span cavern is required with the cavern invert assumed to be located at sea level, suitable locations are areas of topography higher than the +60 mPD contour. The Cavern Land Class IA generally occupies the higher relief areas in the foothills behind the Kowloon urban area. Caverns constructed in this class of land, are unlikely to encounter serious water inflow problem during construction. However, the potential for significant groundwater inflows, subsequent lowering of the water table and the potential for ground settlement will need to be evaluated during a PEGS Study. This class of land has the drawback that suitable access may not be readily available and portal locations and road/tunnel access arrangements become critical factors in establishing a suitable cavern location.

Cavern Land Class I (Drawing No. EG 498) is generally limited in extent as much of the area is already intensively developed. Within the urban area, the likelihood of groundwater inflows, subsequent lowering of the water table and potential for ground settlement will need to be evaluated during a PEGS Study. Also, in coastal areas of lower relief, a cavern of similar dimensions will need to be constructed below sea level, or the amount of overburden cover reduced following detailed investigation. The excavation of caverns beneath sea-level in the vicinity of coastal areas could lead to the ingress of sea water along permeable zones with continual recharge, giving rise to higher ground treatment or dewatering costs and consequent programme delays. Large span caverns which are planned below sea level in coastal areas in Cavern Land Class IB will require careful investigation to ensure that they can maintain water tightness during and after construction. However, this class of land is highly suitable for bulk chemical storage such as oil and gas, which require a permanent water jacket to contain the products in the cavern.

It must be emphasized that both Cavern Land Class IA and IB are considered suitable for cavern development. Despite the fact that caverns constructed in Cavern Land Class IB may encounter serious water inflow on coastal areas, this technical problem can be avoided by careful investigation during the detailed planning stage or overcome by grouting or other ground treatment methods during construction. Planners should realise that the arbitrary subdivision of Cavern Land Class I into IA and IB is for general guidance since an essential factor which governs the choice of alternative sites is the cost of the entire scheme. Technical problems such as high water inflow during construction of a cavern are often small when compared to the benefits of a suitable location with good marine or land access.

It must also be emphasized that the subdivision into Class IA and IB is based on very simple assumptions regarding cavern spans and overburden requirements. These assumptions will be more refined in a detailed PEGS (Figure 2) once the cavern usage is defined and following more detailed geological appraisal.

Drawing No. EG 498 shows some suitable areas within the limits of the existing reclamation. Whilst reclaimed areas are not excluded, this study assumes that any rock cavern development in such areas will be at considerable depths below the existing reclamation within bedrock. Previous discussion regarding increased water inflows in coastal areas is also relevant in this case. In addition, whilst caverns could feasibly be developed under the sea at sufficient depths within rock, for the purpose of this study, undersea areas are excluded as potential sites for cavern development.

3.6 Geographic Information Systems (GIS)

3.6.1 GIS Analysis for Digital Cavern Area Study Map

The Cavern Area Map is derived from a range of data from various sources, both within Government and from Corporations. In the previous Cavern Area Studies (Choy & Styles, 1992; Roberts, 1993, 1994) compilation required time-consuming manipulation and redrawing. Noting that many of the relevant organisations use CAD or GIS technology to manage their data, it was decided to produce the present map using GIS analysis.

Bentley Systems' CAD software, MicroStation 95, was used to reformat the data sets, and to make the final map. GIS analysis was undertaken using Intergraph+s MGE software.

3.6.2 Digital Data Sources and Data Preparation

3.6.2.1 Surface Development

The Kowloon District Office of the Planning Department provided the Outline Zoning Plan information based on the results of a query from its database. The system is implemented on Arc/INFO, however, the results were generated in AutoCAD's dxf format. Results comprised linework and text centroids. The data was readily imported into MicroStation. Minor line cleaning and repositioning of centroids was required before valid topology could be recreated.

3.6.2.2 Underground Installations

There were several sources of data regarding existing underground installations. The MTR Corporation provided many data files in MicroStation format. For their recent projects digital data was comprehensive and a full outline of the MTR Protection Zone was included. However, for the current exercise using a 1:20 000 scale, only the simple axis of the MTR system was used. The MTRC CAD format differs from the Lands Department "standard" (origin and resolution), so data had to be rescaled prior to use.

Data on the Kowloon Canton Railway tunnels, road tunnels, and the Drainage Service Department's new Strategic Sewage Disposal Scheme tunnels are all relatively simple. These were converted or digitised from the Lands Department's Land Information Centre (LIC) maps, or other hard copy sources.

3.6.2.3 Engineering Geological Data

Digital geological data is available from the Geoscience Database of Planning Division, GEO. Fault lines were taken from both the 1:20 000 scale solid and superficial geology map (GCO 1986a, 1986b) and where coverage was available, the latest draft 1:5 000 solid geology maps (GEO, 1996). Faults on the former map were modified by extending coverage beneath superficial deposits.

Photolineaments were taken from the 1:20 000 scale Engineering Geology Map from the Geotechnical Area Study Programme Report (GCO, 1987). Though much of the GASP data has been previously digitised, photolineaments have not. Therefore these had to be digitised for this project. As discussed above, photolineaments are often caused by, and are therefore collinear with, the faults. In cases where faults and photolineaments coincided the photolineament was deleted.

3.6.2.4 Topographic Data

The Lands Department (LIC) 1:20 000 digital topographic maps provided the coastline and the 60 m contour. The 60 m contour on this map set is incomplete as the feature is not mapped through most urbanised areas. Additional data was digitised from the 1:5 000 scale base maps (a set of raster coverage was provided by LIC in Intergraph RLE format), however contours are far from complete for this scale also. The most convenient elevation data available was from GEO's borehole database (Geoscience Database). The elevation data for ground level for some 20 000 boreholes in the Kowloon area provided a satisfactory guide for completing missing segments of the 60 m contour.

Areas of reclamation are not part of this classification scheme for Cavern Area Suitability. However, cavern development under reclamation is discussed, and is therefore shown as a shaded area on the map. A slightly generalised version was taken from the 1:100 000 scale geology map.

3.6.2.5 Study Boundary

When individual themes had been completed they were cut to match the study area outline. Several themes including the Outline Zoning Plan data, reclamation and coastline have near-parallel linework for some area boundaries, for example, along the coast. This was resolved before further processing to reduce "sliver" problems i.e. the very small polygons generated when two nearly parallel lines are overlaid.

3.6.3 Analysis

The spatial analysis required to derive the Cavern Area Suitability Classification from the component datasets is quite straightforward. The classification, and the reasoning behind it, is described in Section 3.7 of this report.

Intergraph GIS software MGE and MGA were used for analysis. Buffer zoning was used to create areas around the line features (faults and tunnels) and area overlay functions were used to classify different parts of the study area according to the criteria. Area-patterner was used to create the coloured or patterned output.

Land not designated as G/IC, O or GB areas on the Outline Zoning Plans is classified as low suitability for cavern development (Class III), irrespective of faulting, nearby underground installations, or elevation. This area is also the most complex topologically comprising a large area containing many complex "islands" and was therefore classified first, so it could be removed from further analysis.

Classification of the G/IC, O or GB zoned land into the Suitability Classes IA, IB, IIA, IIB is based on technical criteria. To do this a single classification overlay was prepared first, and this was then used to subdivide the land into its respective classes.

3.7 The Cavern Area Study (CAS) Map

The Kowloon Cavern Area Study (CAS) Map is shown on Drawing No. EG 498 along with the Cavern Land Class classification scheme (as shown in Table 1). The classification units are distributed as follows:

(a) Cavern Land Class I - This class is defined in Table 1 and is generally of high suitability for cavern development. 30%

of the study area is Class I where 13% is in the higher topography area (Class IA) and 17% is in the low topography area (Class IB).

(b) Cavern Land Class II - This class occupies 5% of the study area, and is generally located within 50 m of faults or underground installations.

(c) Cavern Land Class III: This class occupies 65% of the study area, and has the lowest suitability for cavern development compared with the other classes due to the presence of existing or proposed surface development.

The CAS Map is designed to provide the earliest input shown on the flow-chart in Figure 2. The CAS Map allows the town planner to consider the siting of possible underground facilities at the earliest stages of planning.

Once a possible use is identified by the town planners using the CAS Map, the Geotechnical Engineering Office will carry out a Preliminary Engineering Geology Study (PEGS) to better define a suitable cavern location, propose alternative access arrangements and to estimate the likely cost of cavern construction. An environmental review, financial viability and traffic impact assessment will also be carried out in a planning study coordinated by the Planning Department (Figure 2). This planning study will be in parallel with the PEGS. If all the conclusions are favourable the possible cavern use would then be shown on the Outline Zoning Plan for the area. The next stages will be detailed ground investigations and design stage.

The CAS map shown in Drawing No. EG 498 should be used only as a guide to the general suitability of the terrain for cavern development for regional planning purposes and should not be interpreted, reproduced or enlarged to scales larger than 1:20 000 (i.e. 1:0000 or larger). It is based on general information and assumptions, and should only be used for general planning purposes.

3.8 Other Factors

The CAS Map is intended to provide a general indication for planners of the potential suitability of the terrain for development of man-made rock caverns. However, there are many other factors which must be considered in planning cavern developments in addition to the land ownership and resumption issues which have to some extent been addressed in this study through the definition of Land Class III. These other factors include for example, environmental impact, traffic impact (land and marine) as well as the location of suitable portals and tunnel access to provide connections from the caverns to the ground surface. Detailed discussion of these factors is outside the scope of this study and would be examined during the later feasibility stage in PEGS, and in other planning studies (Figure 2). Useful references can be found in Stauffer (1990), Jansson & Winquist (1977), Nissim (1989) and Subspace Associates (1990).

In addition to the technical and land issues, the viability of a rock cavern scheme should be considered in comparison with the costs of development of above ground options. In the SPUN Study, financial analyses were undertaken on seven schemes of various applications for rock caverns (Ove Arup & Partners, 1989b, 1989c, 1989d, 1990a, 1990b, 1990c and 1990d). It was found in all cases, except for the oil and gas storage scheme, that cavern facilities have higher capital, operating and maintenance costs than above-ground options. However, taking into account the value of land released for other uses, the schemes all become economically beneficial to varying degrees over the long term. In addition to the release of high value land for other purposes, underground options offer substantial environmental benefits for many schemes, such as sewage treatment plants, refuse transfer stations, and water treatment works, a number of such schemes being discussed by Malone (1993). Each scheme will have its own merits or benefits and all schemes should therefore be treated separately.

3.9 Potential Portal Locations

As discussed previously in Section 3.8 there are many factors which must be considered in planning cavern developments. One aspect which needs further consideration is the location of suitable tunnel portals to provide connections from the underground caverns to the ground surface. In previous PEGS undertaken by the Planning Division in GEO, a major cavern location constraint has often been the identification of a suitable area for site formation works and portals for cavern access tunnels. The identification of suitable portal areas will be included in the more site specific PEGS once the need for a specific cavern scheme is identified.

4. DISCUSSION AND CONCLUSIONS

Use of underground space in man-made rock caverns in the Kowloon urban area could provide accommodation for a range of facilities such as sewage treatment and refuse transfer schemes amongst others. This study provides a general indication of areas in which man-made rock caverns could be sited, and is based solely on an assessment of terrain and geological conditions.

The study area is classified into three basic land classes according to the general suitability for cavern development. The classification is based on the location of surface developments, existing underground installations, engineering geological conditions and topographic constraints. The Cavern Area Study Map indicates areas with potential for rock cavern development from a technical point of view. The CAS Map is presented in Drawing No. EG 498, which generally indicates that there are a number of opportunities for cavern development. Of the total study area (43.8 km^2), some 30% is considered highly suitable for caverns, i.e. Cavern Land Class I, with an additional 5% classified as having medium suitability for cavern development.

Clearly, the terrain of most interest to planners will be adjacent to areas of proposed development, although other factors such as environmental impact, traffic impact and the availability of portal areas may impose constraints on cavern development and these issues must be considered in later planning stages.

The Cavern Area Study is the first technical input to the planning process, and the CAS Map is designed to alert planners to the general potential for use of underground space and provide guidance on the suitability of land for cavern development based on simple and valid assumptions. More detailed studies must follow once a possible cavern use has been identified by planners or related professionals.

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LIST OF TABLES

Table 1 - Cavern Suitability Classification

CAVERN LAND CLASS	SUITABILITY	DESCRIPTION
IA	High	Land generally above 60 mPD and at least 50 m from major underground installations or geological faults.
IB	High	Land generally below 60 mPD and at least 50 m from major underground installations or geological faults.
IIA	Medium	Land within 50 m of geological faults. Higher excavation and support costs associated with more difficult ground conditions may occur. May require more detailed site investigation than Land Class I.
IIB	Medium	Land within 50 m of major underground installations. Higher construction costs expected due to constraints on excavation and construction techniques. May require more detailed site investigation than Land Class I.
III	Low	Low suitability due to the presence of existing or proposed surface development which may cause complicated land ownership and resumption issues and may require more difficult cavern engineering techniques.

LIST OF FIGURES

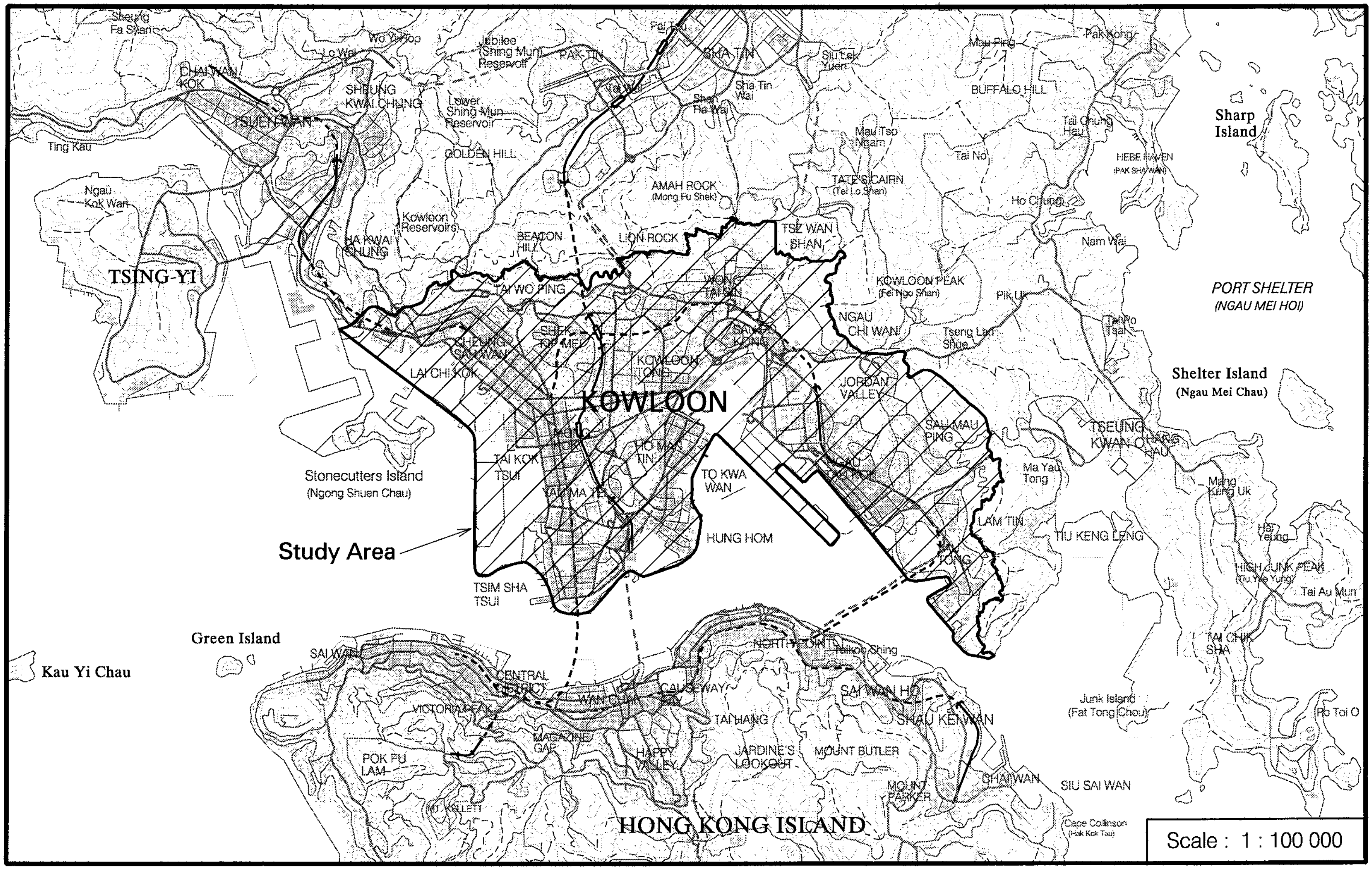


Figure 1 - Location of the Study Area

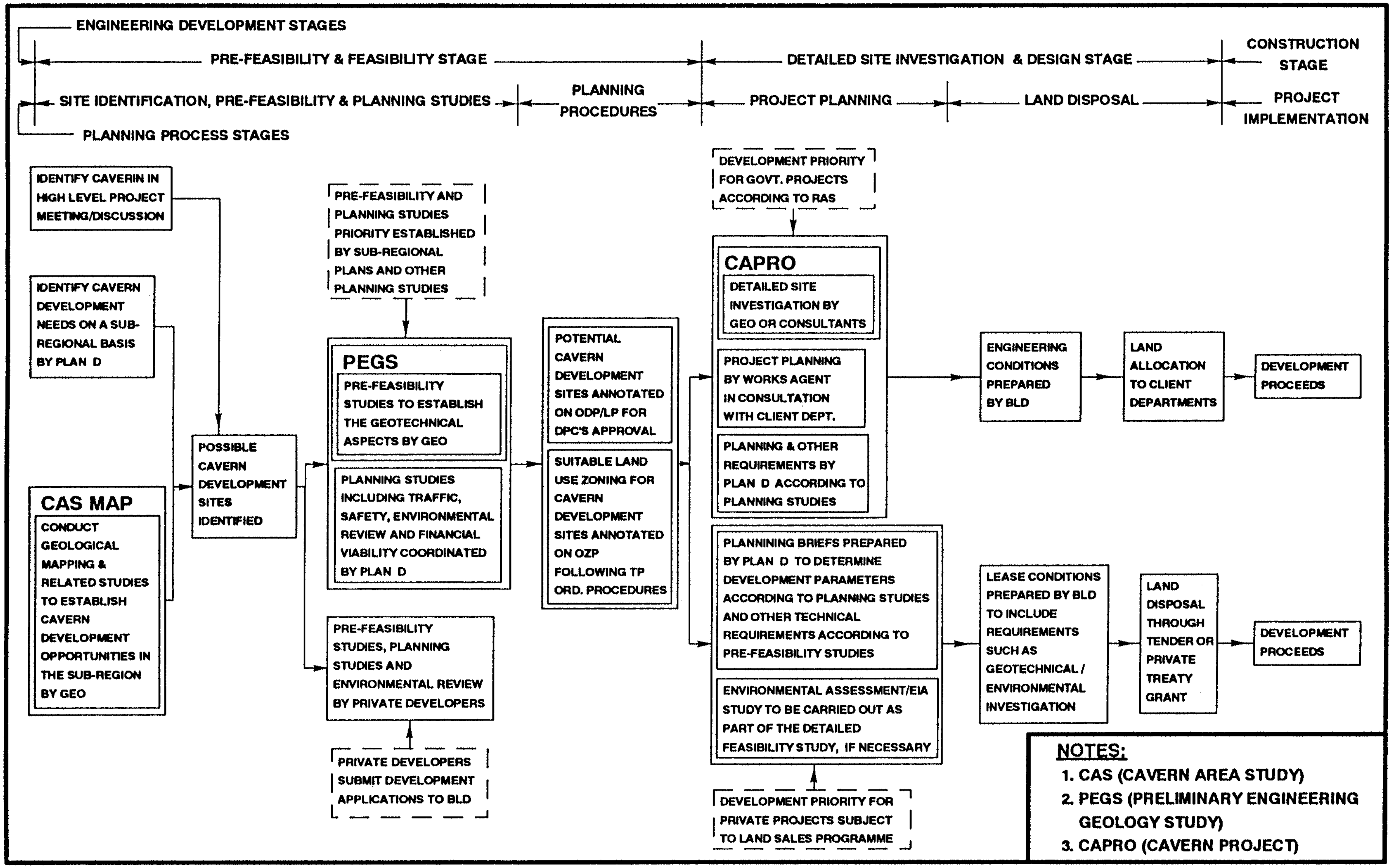


Figure 2 - Planning Process for Rock Cavern Development

APPENDIX A

CHAPTER 11 OF HONG KONG PLANNING STANDARDS AND GUIDELINES

CHAPTER 11 MISCELLANEOUS PLANNING STANDARDS AND GUIDELINES

CONTENT

Section 2 Approved by LDPC on 10.9.91 (LDPC Paper No. 24/91)
Section 3 Approved by LDPC on 17.10.91 (LDPC Paper No. 28/91)

MISCELLANEOUS PLANNING STANDARDS AND GUIDELINES

1. Introduction

1.1 The purpose of this chapter is to provide planning standards and guidelines for those land uses or facilities which do not fall within the purview of other chapters. These facilities and land uses are not at present related to each other. However, some of them may be expanded or combined in future to form new chapters of their own. As such, this chapter may be expanded or curtailed to suit new requirements.

2. Underground Rock Cavern Development

2.1 Rock Cavern Development Opportunities

2.1.1 Underground rock cavern developments refer to developments inside large man-made underground spaces in rock. Hong Kong's geological conditions offer excellent opportunities for this type of development. The igneous rocks which underlie much of the metropolitan area and the New Territories are excellent excavation media below the weathered mantle and are ideal for forming man-made caverns. Caverns are designed on the principle of utilizing the strength of the rock mass to form the roof arch and sidewalls. Detailed guidance on site investigation, design and construction of caverns would be given in Geoguide 4 - Guide to Cavern Engineering.

2.1.2 Although most cavern developments incur higher capital costs than similar developments above-ground, the use of cavern space in highly developed and overcrowded areas of Hong Kong can be an economic proposition under certain circumstances. Examples of such cases are given in the detailed reports of the Study of the Potential Use of Underground Space (SPUN).

2.1.3 Underground cavern developments can also be an attractive alternative development form, in terms of potentially significant environmental benefits. These benefits include the potential to mitigate adverse environmental impacts associated with conventional surface developments of certain polluting uses and the provision of a very stable environment, which can achieve savings in running costs.

2.2 Possible Uses in Rock Caverns

2.2.1 Table 1 shows the possible uses of rock caverns suggested by the SPUN study consultants and recommended by the inter-departmental Working Group on Underground Rock Cavern Developments. The table is not exhaustive and should be used for general guidance only. Each application has to be considered on its own merits.

2.2.2 It must be recognised that changes in technology may help prevent or alleviate problems associated with the intended underground development. The suitability of each case should therefore be assessed on the basis of a pre-feasibility study and planning study described below.

Table 1 : Possible Uses for Rock Cavern Development

Land Use	Possible(1)	Unsuitable (2)
1. *Residential*		
(Incl. 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	*	
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 & networks	*	
Cemetery/Crematorium		*
Columbarium/Mausoleum/Mortuary	*	
9. *Utilities*		
Power stations/Electricity sub-stations	*	

* SPUN's and Working Group's recommendations

(1) Uses under this column are subject to pre-feasibility studies and planning studies to establish their suitability for development on a case by case basis.

(2) Uses under this column are usually considered unsuitable for underground rock cavern development.

2.3 Planning Process for Rock Cavern Development

2.3.1 The planning process for handling rock cavern development is illustrated in the flow chart at Figure 1. It indicates the role of the Planning Department (Plan D), the Geotechnical Engineering Office (GEO) of the Civil Engineering Department (CED), the Buildings and Lands Department (BLD) and other relevant departments/agencies in the planning and development of underground rock caverns.

Site Identification

2.3.2 Possible underground rock cavern sites should be identified as solution spaces mainly in the formulation of the sub-regional planning strategies. Other special strategic studies may also identify suitable cavern sites to meet their objectives or requirements. Site identification is through systematic geological mapping by the GEO or other study agents, who should work closely with the Plan D to establish the need for cavern development and the intended uses.

Pre-feasibility and Planning Studies

2.3.3 The purpose of conducting pre-feasibility and planning studies is to provide basic technical and planning information about the sites and an estimate of capital costs of development. The pre-feasibility studies will be carried out by the GEO and the planning studies co-ordinated by the Plan D. Such studies will safeguard against wastage of manpower and resources at the project planning stage and should normally be conducted before projects are proposed for inclusion in Cat. C of the Public Works Programme.

2.3.4 Pre-feasibility studies are the initial appraisal of the geotechnical and engineering aspects of the cavern site for the proposed use. The study should produce preliminary design of cavern accommodation and an estimation of rock excavation and support costs.

2.3.5 The purpose of planning studies is to assess the viability and development parameters for the scheme which include:-

(a) Use

The study should provide justifications for the intended use. Any potential conflicts between the schemes and their immediate environment should be properly addressed in the planning study.

(b) Environment

For projects which are likely to cause a significant impact on the environment (see para. 1.7, tables 1.1 & 1.2 of Chapter 9 for reference), the Environmental Protection Department should be consulted. The necessary procedures to be followed are discussed in Chapter 9 of the Hong Kong Planning Standards and Guidelines and summarized in a L&WB Technical Circular No. 9/88 "Environmental Review of Major Developments" for public works projects and in the Environmental Protection Department Advice Note no. 2/90 "Application of the Environmental Impact Assessment Process to Major Private Sector Projects" for private cavern development. The necessary preventive measures to mitigate the adverse environmental effects of the projects should be identified. In some cases quantitative environmental assessment may be required to determine the magnitude and severity of potential impacts, prior to any in-principle decision on the project.

(c) Safety

The safety aspect of the cavern site should be adequately assessed in the initial planning stage. The study should take into account the overall size of a cavern which would have a direct effect on the ease of evacuation and on the safe use of the development.

(d) Traffic

A traffic impact study should be conducted to address the effect of the intended development at both construction and operation stages. Interfaces and connections with the existing and planned roads, railway and other forms of transportation system should be examined.

(e) Financial

For government projects, the user department, in consultation with relevant departments, will be required to submit a cost/benefit analysis of the scheme taking into consideration the additional costs, if any, of development underground and the potential financial and other benefits including the release of space above-ground for other uses. For private projects, a statement giving the development costs and appraisal on the financial viability will be required as part of the submission for planning approval.

Planning Procedure

2.3.6 Once the viability of a cavern development has been ascertained, site reservation can be made on the relevant Outline Development Plans/Layout Plans and Outline Zoning Plans in accordance with the normal planning procedures. Suitable zonings should be annotated on these plans to indicate the above-ground and underground development intentions as there may be different developments occupying the same site. At this stage, only the approximate boundaries of the underground rock cavern sites can be annotated.

Project Planning

2.3.7 Project planning for public sector works usually starts when the proposed development has been upgraded to Cat. B of the Public Works Programme. At this stage, detailed geotechnical investigation is required. For government projects, the user department or its works agent will proceed with detailed studies in accordance with the planning requirements previously identified and the project requirements. Detailed guidance on investigation and design of cavern developments would be given in Geoguide 4 - Guide to Cavern Engineering and the Code of Practice on Fire Engineering for Caverns. Both documents are under preparation. Relevant issues to be considered include :-

(a) Fire, Hazard and Public Safety Issues

Fire/hazard prevention, means of escape and other public safety issues are of crucial importance to the design of cavern developments. The Director of Fire Services and the Principal Government Building Surveyor should be consulted on their requirements.

(b) Radon Emission and Gas Incidence

It is standard practice in the design of all underground space to provide adequate ventilation in order to avoid the accumulation of gas. The Director of Environmental Protection, the Director of Fire Services, the Commissioner for Labour and the Director of Health should be consulted on their requirements.

(c) Blasting Noise, Vibration and Subsidence

Some cavern schemes may require blasting in close proximity to building structures and transport lines. When such operations are likely to be involved, advice on the stability of adjoining structures and requirements for preventive measures where necessary should be sought from the Mines Divison of GEO and relevant authorities/ departments.

(d) Drainage, Servicing and Other Utility Provisions

Consultation with the Director of Drainage Services, the Director of Water Supplies and other utility companies should be made on their requirements on the provision of utility facilities to the cavern development.

For private projects, a planning brief will be prepared by the Plan D to list the development parameters and the above technical requirements. The planning brief will be used as the basis for drawing up the lease conditions.

Land Disposal

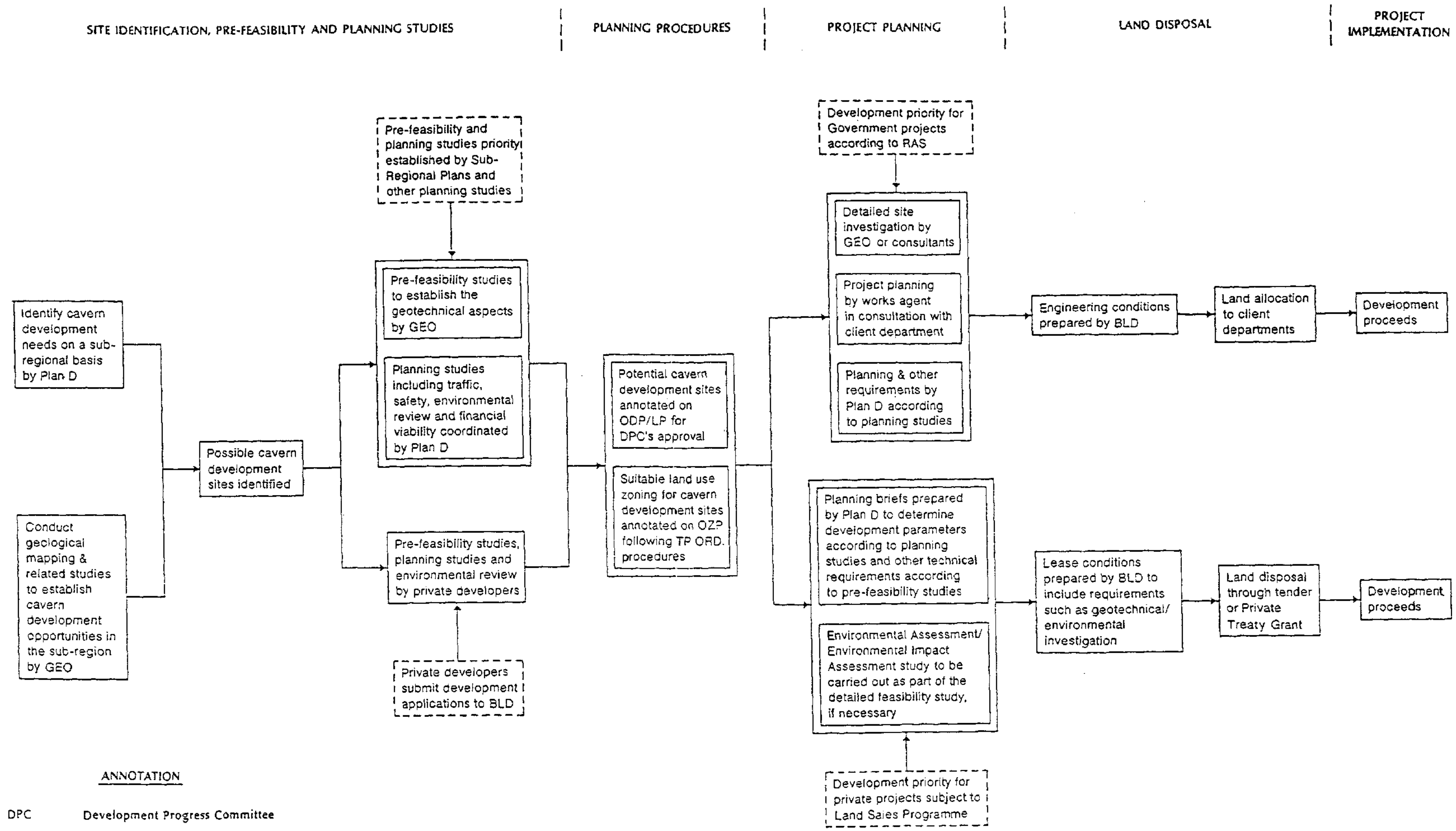
2.3.8 The disposal of land for underground cavern development will follow current procedures either as a land allocation for public projects or a land sale/grant for private projects. Land sold/granted for private cavern projects would be counted towards the annual land sale quota.

2.3.9 Due to the complexity of space which cavern developments usually incur, there are practical difficulties in defining plot ratio and site coverage. The development content and relevant control on the cubic content of the development should ideally be specified in the form of a three dimensional development 'envelope' on the lease/engineering conditions. This 'envelope' should be developed in consultation with the GEO and should define an inner space within which cavern construction is permitted, and an outer surrounding space (for maintenance of cavern support) within which excavations or other works should not be permitted apart from access tunnels, drainage adits, and ventilation shafts. Relevant departments should be consulted on the maintenance requirements of the proposed development for incorporation in the engineering/lease conditions.

Project Implementation

2.3.10 All private cavern projects should follow the normal works approval procedures as surface developments. Relevant submissions and approvals are to be co-ordinated by the Building Authority in consultation with other departments. Caverns or any underground space adopted or constructed for occupation for any purpose, including associated access tunnels and access shafts, are considered to be buildings under Section 2(1) of the Buildings Ordinance. For public projects, the works agent would be required to comply with the Engineering Conditions for the land allocation.

2.3.11 To secure the operation and structural safety of the rock cavern development, a protection zone covering an area surrounding the development would be defined by the private developer or Government's works agent following detailed design and construction of the cavern. The GEO should be consulted on the proposed extent of the protection zone. The protection zone would be annotated on the ODP/LP and relevant departments, in particular GEO and BOO, should be consulted for any future development proposals traversing this zone.



ANNOTATION

DPC	Development Progress Committee
Plan D	Planning Department
BLD	Buildings and Lands Department
GEO	Geotechnical Engineering Office
LP	Layout Plan
ODP	Outline Development Plan
OZP	Outline Zoning Plan
RAS	Resource Allocation System
TP ORD	Town Planning Ordinance

FIGURE 1 : PLANNING PROCESS FOR ROCK CAVERN DEVELOPMENT

LIST OF DRAWINGS