Developing Hong Kong's First Materials Testing Laboratory and Archives Centre in Caverns - Technical Challenges and Solutions

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ABSTRACT

In Hong Kong, cavern development is entering a new era, from a narrow range of uses in the past to the recent widespread applications in the territory (Ho et al. 2020). Rock caverns are now engineered to become a viable source of land supply for sustainable development of Hong Kong. With four decades of knowledge and experience accumulation, Hong Kong has proclaimed its readiness in taking on a new path following the launch of the award-winning Cavern Master Plan along with a suite of enabling measures to foster wider applications of rock caverns in Hong Kong. A number of cavern projects are in the pipeline, covering not only traditional "Not In My Back Yard" (NIMBY) uses but also some new types of facilities. Among all, the Geotechnical Engineering Office of the Civil Engineering and Development Department is now undertaking a joint cavern development project at Anderson Road Quarry Site, which involves two first-of-its-kind cavern facilities in Hong Kong — a materials testing laboratory and an archives centre. This paper will introduce the background of the project and use it as an illustration to highlight various challenges encountered when housing facilities in caverns, such as operation requirements of the facilities, fire safety considerations, site constraints, and the need for preserving the future potential of Strategic Cavern Area concerned. This paper will also discuss some novel design approaches contemplated and other potential solutions to tackle these challenges.

Keywords: Rock Caverns, Underground Planning, Modular Integrated Construction, Hong Kong

1 Introduction

The Joint Cavern Development project at Anderson Road Quarry Site comprises two government facilities, namely the Public Works Central Laboratory (PWCL) of the Civil Engineering and Development Department (CEDD) and the Archives Centre (AC) of the Government Records Service (GRS). These facilities, given their nature and requirement for a stable environment, are particularly suitable to be housed in rock caverns.

The Public Works Laboratories of the CEDD comprise PWCL and five Public Works Regional Laboratories (PWRLs). The Public Works Laboratories, including the PWCL and five PWRLs, are accredited by Hong Kong Accreditation Service under the Hong Kong Laboratory Accreditation Scheme (HOKLAS) for testing and calibration services. The quality management system of Public Works Laboratories meets the requirements of international standard ISO/IEC 17025. Pursuant to the policy directive as set out in WBTC No. 14/2000, the Public Works Laboratories are to provide quality testing services in the capacity of an Employer laboratory and to ensure that reliable, efficient and effective construction materials testing is accessible to all public works projects.

The PWCL is currently accommodated in a four-storey purpose-built building at Cheung Yip Street, Kowloon Bay, with a site area of 3850 m^2. A picture of the existing PWCL building is shown in Figure 1. The total covered floor area of the building is 7088 m^2 with a usable area of 5782 m^2. The PWCL offers an extensive range of compliance and investigative testing services, covering soil and

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rock tests, concrete and cement tests, general materials and steel tests, chemical tests and calibration services.

In the past few years, the Public Works Laboratories delivered about 600,000 tests/year on average on various construction materials. Apart from routine testing, the PWCL also provides expert testing services to forensic investigations and sets technical standards for construction material testing in Hong Kong (e.g., Geospec 3, CS1, CS2 and CS3). Furthermore, the PWCL undertakes technological development work relevant to construction materials and devises new testing techniques and standards to meet industry needs. The laboratory compartment is equipped with special ventilation provisions, dangerous goods stores and loading bays. Currently, there are about 120 staff working in the PWCL Building.

Figure 1: Existing PWCL Building at Kowloon Bay

It was stated in the 2013 Policy Address that the Government would take forward the initiative of rock cavern development as a viable source of long-term land supply. As the existing site occupied by the PWCL Building will be made available for land disposal in years to come, it has become the Government's target to relocate the PWCL and release the site in the future. Throughout the process, it is essential to maintain quality, efficient and effective construction material testing services for public works projects in Hong Kong.

The other government facility to be housed in Joint Cavern Development caverns is the GRS' AC. Records are valuable resources of the Government. They are evidence of decisions made, support for operational and regulatory requirements and are essential for an open and accountable government. GRS, established in 1989, is tasked to oversee the overall management of government records and ensure that government records are properly managed and those of archival value are selected for preservation and public access. At present, GRS is providing archival facilities for public records, i.e. records appraised as having historical value for long-term preservation. The Public Records Office of GRS is responsible for appraising and acquiring government records and material of enduring value and making them available for public inspection. A photo of the Public Records Building at Kwun Tong and one of its archival repositories are shown in Figure 2. The Public Records Office offers a rich heritage resource consisting of documents, photographs, movies, posters and other records tracing the governance and evolution of Hong Kong. These archival records are stored under tightly controlled climatic conditions in terms of temperature, relative humidity and light for protection against deterioration such that they could be preserved and retained permanently, and are available for public viewing. The current storage capacity of the Public Records Building at Kwun Tong is close to saturation. To increase the maximum capacity in meeting the expected storage demands of government archival materials in the future, there is an imminent operational need to expand the existing archival storage facilities by means of building a new AC in caverns.

Figure 2: Public Records Building at Kwun Tong and one of its archival repositories

2 Incentives to Adopt Cavern Option and Selection of the Suitable Site

Surface land is a scarce resource, particularly for those in the urban area. A parcel of land should always be planned for the most effective and beneficial land use taking into account socio-economic needs, demand-supply balance, engineering factors and various district and regional land development considerations vis-à-vis the nature of the planned facility.

Based on the findings of CEDD's study on "Long-term Strategy for Cavern Development" completed in 2018, PWCL and GRS' AC are two potential facilities highly suitable to be housed in caverns (Ho et al. 2020) with reasons below: -

(i) Preservation of valuable surface land for other beneficial use

Both facilities require the occupancy of a relatively large floor area with limited flexibility for vertical development due to operational needs (e.g., efficiency in testing material delivery in PWCL and inventory arrangement / retrieval logistics in AC, both of which are essential for providing quality service). A convenient centralised location is preferrable for the ease of access by facility users. However, any large surface land in urban area would be better utilised for other higher priority usages, such as residential developments. The cavern option allows surface land to be designated for other value-added developments.

(ii) Stable environmental condition

The stable environment in rock caverns is ideal for laboratory testing operation and storage of testing specimen (e.g., sheltered from shock and vibration, constant humidity, steady temperature, etc.). These conditions are also advantageous to the storage of archival holdings. In an ordinary surface building, a large amount of energy is required for indoor climatic control in order to satisfy the stringent preservation requirements of the archives repositories. The stable humidity and lower temperature in caverns are beneficial to operate the facilities in a higher energy efficient manner, hence is more environmentally friendly and will cost less in the long run.

(iii) Isolation from the surface

Some of the tests and calibration process as well as fragile items from the archival holdings are sensitive to vibration. Rock caverns offer a natural isolation which can effectively shield off / minimize the vibration caused by adjacent users.

(iv) Flexibility for future extension

Due to higher public expectation for enhancement in quality service of the Government with time, there is an increasing demand for preservation of heritage resources in archival repositories and for public inspection (for GRS' AC) and more space is required for advanced laboratory testing by automation and expansion of service (for PWCL). Surface buildings in an urban setting are usually surrounded by occupied buildings, infrastructures, utilities, etc. These physical constraints, together with the potential construction impacts as well as other planning and development restrictions, would normally increase the difficulty, hence the cost and time, for any further extension. Caverns, if under a proper initial planning, would allow a higher flexibility in layout design which facilitates future expansion.

After deciding on the cavern option, a site identification and selection exercise was carried out during the feasibility studies. Considering a basket of factors including operation and location requirements of the facility itself, site characteristics (e.g., planning conditions, accessibility, geology, hydrogeology, traffic, environmental aspects, etc.), project programme and cost for development, etc., Tai Sheung Tok overlooking Anderson Road Quarry Site Development was selected as the most cavern suitable location for relocating the PWCL and building the new AC. This site falls within the Strategic Cavern Area (SCVA) No. 28 of the Cavern Master Plan (CEDD 2017). The selected site at SCVA No. 28 and the preliminary footprint layout of the Joint Cavern Development project is shown in Figure 3.

The schematic design of the Joint Cavern Development project comprises four main caverns in 3 to 4 floor levels with portal structures of similar heights. The rendering of the outline scheme is shown in Figure 4 for illustrative purpose. Preliminarily, the size of the caverns would be 30 m (H) x 90 m (L) with span ranging from 30 m to 35 m. Offices and the necessary mechanical plant rooms are planned at the portal structure while the laboratory testing areas and archive repositories will be accommodated inside the main caverns.

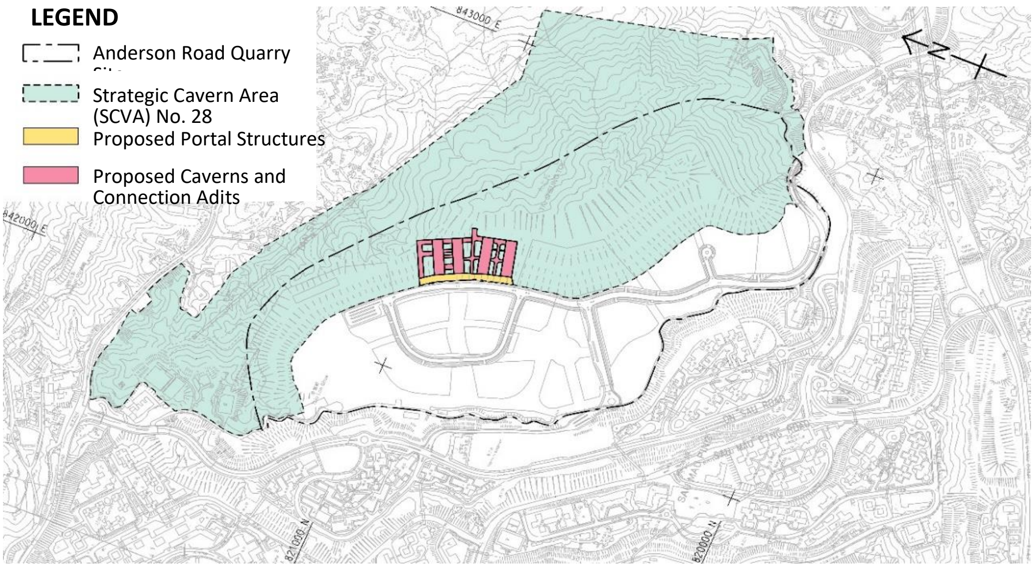

Figure 3: Location plan showing the selected site at SCVA No. 28 and the preliminary footprint layout of the Joint Cavern Development project

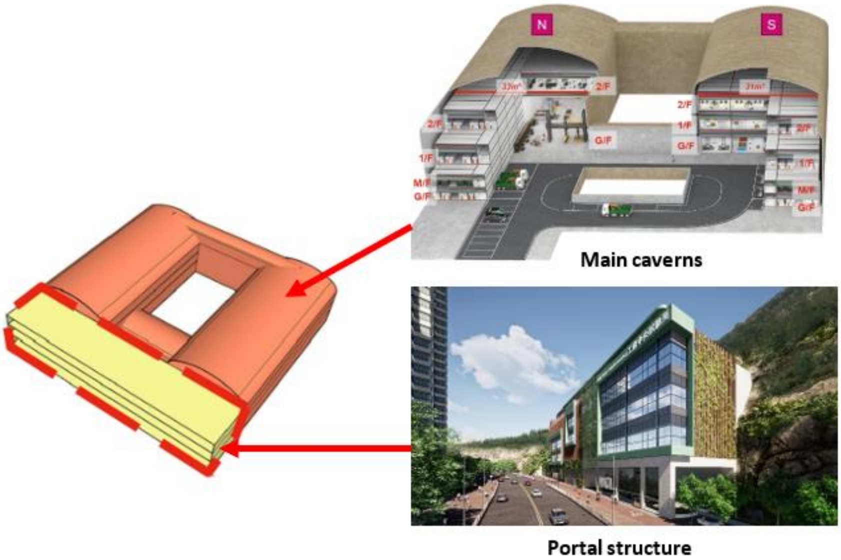

Figure 4: Indicative model of main caverns and portal structure

3 Challenges of Cavern Development

Since 1980's, the Government has successfully implemented a few cavern projects in Hong Kong, including the Stanley Sewage Treatment Works, Island West Transfer Station and Western Salt Water Services Reservoirs. Although cavern development is not new in Hong Kong, caverns were mostly used to house limited types of facilities (mainly NIMBY) in the past. The issue of the Cavern Master Plan has provided more opportunities for extended land use in caverns. In the Joint Cavern Development project, the relocated PWCL will be the world's first cavern material testing laboratory of such scale and the new AC will pioneer cavern archives facilities in Asia Pacific.

Along with these extended uses, new challenges also emerge. One of them is the applicability of prevailing design codes and practice to these new types of facilities. For instance, the Guide to Fire Safety Design for Caverns 1994 (BA & FSD 1994) sets out the design rules for rock caverns intended for low population occupancy (e.g., those for public utilities in the 1980's). There is also a lack of established fire safety guidelines and regulations tailored for the current purpose in overseas countries with advanced application of rock caverns. It is considered not appropriate to apply directly local and overseas fire safety codes to the Joint Cavern Development project or any other cavern facilities of similar scale in terms of population occupancy. A customised fire safety guideline based on sound fire engineering principles has to be tailored for these projects. In this connection, the establishment of an appropriate vetting mechanism is also required to ensure top-level design for fire safety in all relevant aspects.

The biggest project-specific challenge is the extremely tight development time frame in relation to (1) the staged population intake schedule of the residential housing at Anderson Road Quarry Site Development from mid-2023 to 2026 tentatively and (2) the target land disposal schedule for the site occupied by the existing PWCL Building at Kai Tak. In short, every stage in the Joint Cavern Development project is competition against an extremely aggressive programme.

There are still site-specific challenges at Tai Sheung Tok in spite of its favourable factors for cavern development (e.g., geology, accessibility, readiness of development, etc.). The construction team has to resolve the problem of limited work areas near the proposed portals and within the network of caverns and connecting adits while racing for progress under a tight programme. Innovative construction methods are called for to enable work on multiple fronts with a view to achieving programme merits.

Land, both surface and underground, is a valuable yet expendable asset. In every cavern development project, sustainability is of the essence given the limited length of available portal access versus the comparatively large developable cavern space. It is HKSAR Government's policy to safeguard the development potential of SCVAs. Taking SCVA No. 28 as an example (Figure 5), once the whole lengths of the three potential portal areas are depleted, further cavern development by other project proponents or extension of completed caverns will become extremely difficult if not impossible. As such, suitable enabling measures have to be explored and implemented to safeguard the future development potential of the unused space. Such provisions to foster sustainable and continuous rock development will form part of the current project.

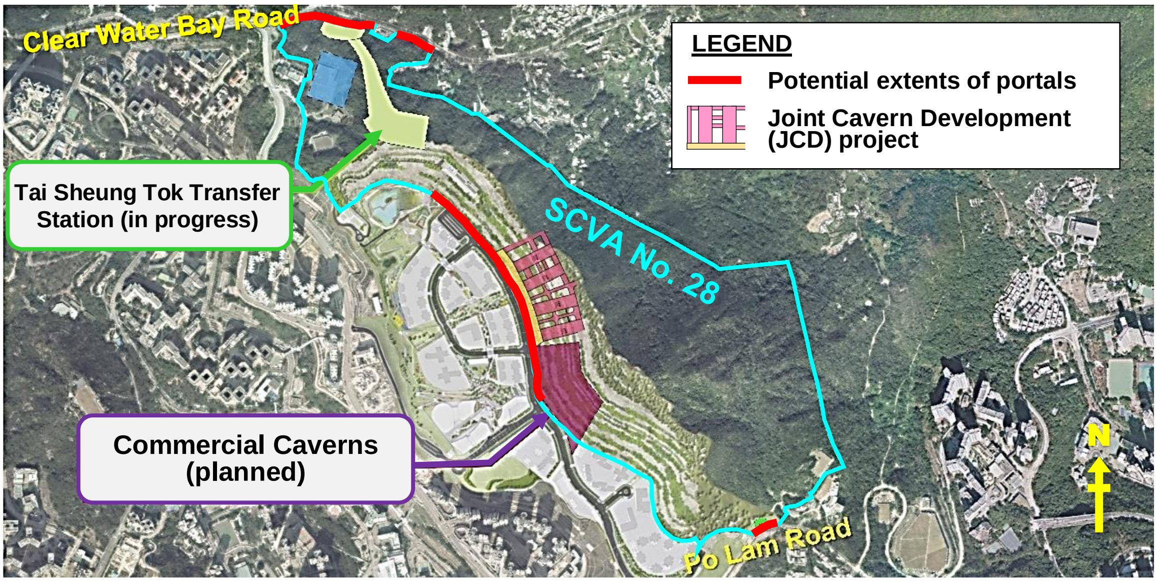

Figure 5: Extent of potential portal locations of Strategic Cavern Area No. 28 and the planned / ongoing cavern projects

4 Bundling Arrangement

PWCL and GRS' AC were initially two distinct projects. The CEDD has coincidentally undertaken as the works agent for both projects. In separate site identification and selection exercises, Tai Sheung Tok was chosen as the suitable site for both facilities, because of similar location requirements (e.g., centralised with good accessibility) and operational needs (e.g., stable environment). In working out the implementation plans for the PWCL project and the AC project, the following are observed: -

(i) Similar nature of works — both projects are cavern development to house government offices and facilities;

(ii) Project implementation time frame largely overlapped with staggered completion;

(iii) Extremely close geographically (i.e., with project boundary adjoining each other) — significant construction challenges in interface coordination, resources planning and constraints in division/sharing of works area; and

(iv) The need to install full noise enclosure before first population intake scheduled for mid-2023 at Anderson Road Quarry Site to mitigate the environmental impact during the construction stage of the projects.

With due consideration to the above, the most effective project delivery approach is to adopt a combined arrangement, so as to tackle the above-mentioned construction challenges and to achieve synergy effects. One significant benefit of this bundling arrangement is the reduction in consultancy and contract administrative efforts. It is also envisaged that there would be savings related to economies of scale in excavation volume, shared use of building services provisions, optimisation of cavern size, etc.

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In particular, a single consultancy agreement covering both the PWCL project and AC project can facilitate design coordination and harmonization, optimise cavern design and layout (e.g. reduction of excavation volume, better layout of the connecting tunnel, etc.), reduce study efforts on technical aspects of similar nature and maximise cost-effectiveness.

Delivering the works of both facilities under one contract can minimise works interfaces and enable better planning and site coordination, which is beneficial to systematic safety planning and implementation of impact mitigation measures particularly in a congested site environment. There will be more efficient deployment of contractors and supervision teams. A single contract can also reduce the risk of programme delay.

5 Use of Modular Integrated Construction (Mic) in Caverns

Unless for special reasons, it is normally conducive to take forward cavern excavation and construction of the associated building (including portal building if any) in an integrated manner. This requires more comprehensive consideration of design, construction, operation and maintenance aspects for the whole facility.

The adoption of MiC is one of the key measures for meeting the tight programme. On-site cavern formation and off-site manufacture of structure modules at the MiC yard are to be carried out in parallel. Using MiC inside caverns to build a structure of such a scale is unprecedented in the world. Innovative ideas are called for to tackle the challenges, including headroom limitation in caverns, logistic planning, customised room requirements vis-à-vis standardised units, design for fire safety and space optimisation, etc. In particular, a material testing laboratory housed in caverns demands stringent environmental control, sophisticated ventilation system, ample fire service installation, exhaust gas emission control from experiments, etc. Archive repositories require a high-rate temperature and humidity control system for preservation of valuable archival records, an effective automatic storage/retrieval system, and a custom-made fire safety system of high reliability. The MiC must be able to incorporate/accommodate all these features.

6 Application of Early Contractor Involvement (ECI)

In the engineering industry, the expertise of MiC lies with the contractors and their suppliers. To ensure effective use of MiC and reaping its greatest benefits, ECI is introduced. It is intended to bring about constructive proposals that would allow refinement of the Employers Requirements, which may in turn enhance the overall buildability and achieve greater certainty in the works programme. In this project, an ECI stage is included between the prequalification stage and the tendering stage. The ECI process would allow the Government to capture contractors' expertise in approaching the technical challenges envisaged for this project.

7 Provision of Enabling Adits

Today, several cavern projects are under planning at SCVA No. 28 (Figure 5). These projects plan to utilise, as construction portal, and subsequently occupy, as portal buildings, the two portal areas facing Clear Water Bay Road to the north and the one facing Anderson Road Quarry Site to the southwest, leaving a relatively small portal facing Po Lam Road to the south. One can easily imagine that, upon the completion of these projects, two of the three portal areas will be fully occupied. The remaining portal in the south can hardly support any extensive development due to its small size (i.e. limited work space and difficulty in mucking out), long distance from the centre of the SCVA, i.e. space with sufficient rock cover for cavern development of larger scale.

Population intake at Anderson Road Quarry Site Development is anticipated to commence in mid-2023 with full intake after 2026. This adds to the challenges. Construction of additional portals at existing rock slopes, which needs the setup of blast doors and noise enclosures before any drill and blast operation can take place, will be extremely difficult if not impossible in view of the noise and vibration caused by mechanical excavation. From the perspective of preservation of the development potential, a project should be aware of such constraint to any subsequent projects in this SCVA. To address this, one should consider the potential implication of his proposal holistically and strategically and reserve/provide the necessary measures to safeguard the future cavern development potential in order not to jeopardise effective use of cavern space in general.

In the Joint Cavern Development project, the detailed proposal for safeguarding measures is still being developed. One of the preliminary ideas is to provide reserve tunnels or retain the construction adits as enabling works of future projects. The layout and alignment of these tunnels/adits would be designed meticulously such that, whereby achieving the objective of SCVA preservation, the work front or blast face in particular, is sufficiently far from the commissioned PWCL and AC. This essentially reduces the risk of excessive vibration due to future construction to PWCL and AC vibration-sensitive operations. Also, as the reserve tunnels/construction adits will probably serve as the mucking out point during cavern construction in the future, their locations should be chosen strategically to minimise the potential construction traffic impact towards the local community.

The above is only one of the many options that may fulfil the SCVA preservation requirements as set out by the Government. It is always worthwhile to explore other innovative measures, or by integration of more than one option, in the upcoming phases of the Joint Cavern Development project. Despite details of measures will vary by projects, the essence is to foster sustainable caverns development within the SCVA concerned during the early stage of a project.

8 Rock Reinforcement Approach and New Construction Material

The concept of Rock Reinforcement Approach (RRA) is to mobilise the strength of rock to form a natural rock arch with adequate stability. The common support elements comprise (1) rock bolts which tie the rock blocks together to form an arch, and (2) a layer of sprayed concrete which provides a confinement pressure on the rock face. The lining system adopting RRA is illustrated in Figure 6.

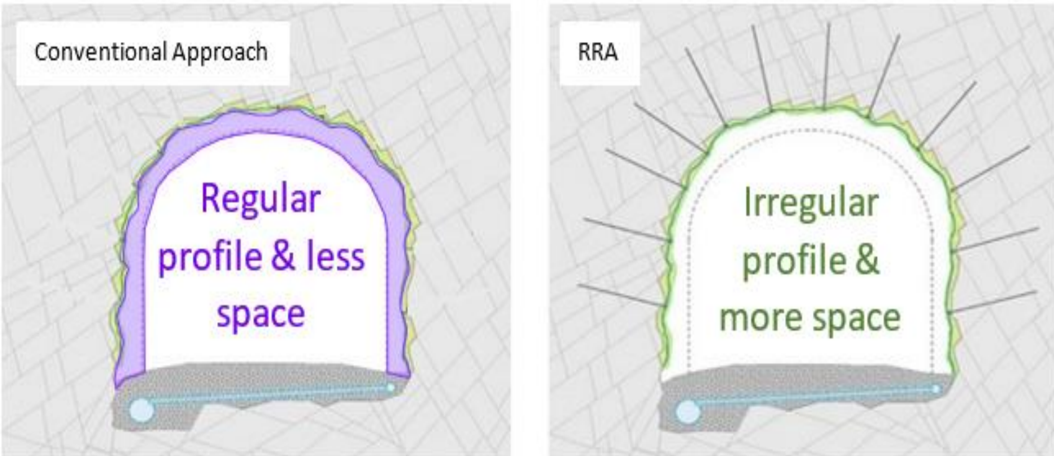

Figure 6: Illustrative diagram for the concept of RRA

In Hong Kong, it has long been a common practice to adopt cast-in-situ concrete lining as the permanent support of tunnels/caverns, no matter whether there is a shotcrete/sprayed concrete lining (i.e., the first pass lining) serving as the temporary support or not. It is totally understandable that in the past, local practitioners might find the support contribution by sprayed concrete lining skeptical, thereby neglecting it, due to immature technique and lack of internationally-recognised standard and specifications then. However, engineering knowledge also tells us that competent rock mass could be stronger and stiffer than artificial material. A design taking into account rock strength contribution will be more rational.

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Following the improvement of sprayed concrete technique in recent years, high quality sprayed concrete lining had been constructed in tunnel projects around the world, including the renowned Crossrail project in UK (Stark et al. 2016). While the international counterparts are consolidating their experience in literatures and publications (e.g., Thomas (2009), the series of papers in ICE's 5 volume set publication for the Crossrail Project (Crossrail 2016), etc.), the local industry is left with some easier tasks by specifying the sprayed concrete for tunnel/cavern use and the local application of the RRA.

Riding on the successful application of the RRA in Drainage Services Department's project to relocate Sha Tin Sewage Treatment Works to caverns, the Joint Cavern Development project team aims for enhancing the application of RRA. Among the potential options, the most promising is the application of composite lining concept. By applying this concept, the first pass lining will form part of the permanent works, and the overall lining thickness could be reduced. Given the same usable space in the completed structure, the total volume of rock requiring excavation could be reduced.

In order to implement this approach, suitable specifications on the first pass lining with reference to relevant international practice have to be developed. One of the key concerns that led to the disregard of first pass lining in the past was the potential damage caused by subsequent blasting vibration to the completed portions. To ensure the structural integrity of the first pass lining, the CEDD has initiated a study on the development of a Vibration Resistant Sprayed Concrete (VRSC). It is of aspiration that the novel material could have stronger resistance against blasting vibration such that the sprayed concrete lining using this material could withstand rounds of blasting operation and remain intact and durable for permanent use. The development of VRSC is still in progress. Trial use and full application of the material as sprayed concrete lining are probable in the Joint Cavern Development project depending on the time frame for material development in times to come.

9 Conclusions

The Joint Cavern Development project is a pioneer project which realises the initiative of versatile use of caverns. Rock cavern is regarded as a valuable source of land supply in the middle to long term, contributing to alleviation of the intense demand for surface land in Hong Kong. It is envisaged that by expanding the potential applications of rock caverns to house wider range of government facilities, more surface land could be released for other beneficial uses.

The Joint Cavern Development project at SCVA No. 28 involves two first-of-its-kind cavern facilities in Hong Kong — a materials testing laboratory and an archives centre. This paper illustrates the challenges of the Joint Cavern Development project, including the extremely tight implementation time frame, site constraints, project interfaces, fire safety considerations, novel construction techniques and technical design requirements arisen from pilot applications of design concepts and unconventional project implementation strategies, and the way-forward options which aim at surmounting the challenges and at the same time creating synergy for cost-effectiveness and minimising the risks of programme delay.

It is our mission to ensure the sustainability of cavern development where strategic planning and implementation of enabling measures are highly necessary. To this end, it is always important to maintain holistic considerations for the implications on future development potential of the SCVA concerned. The spirit of cavern development is to be progressive and systematic, in lieu of individual project-based implementation.

10 Declarations

10.1 Acknowledgement

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