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INNOVATIVE PRACTICES AND SUSTAINABLE DEVELOPMENT FOR CAVERN DESIGN AND CONSTRUCTION BASED ON THE Q-SYSTEM AND ROCK REINFORCED APPROACH

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Abstract: The Guangdong-Hong Kong-Macao Greater Bay Area (GBA) is advancing decisively towards high-quality development goals. The Cavern Master Plan (CMP) launched by the Hong Kong Government exemplifies innovative underground space development emerging from this strategic context. This paper focuses on a cavern project, one of the largest in Hong Kong, featuring a maximum excavation face span of 36.2 meters. Using this project as a case study, it systematically investigates the application of the Q-system, Rock Reinforcement Approach (RRA), and construction optimization under complex geological conditions. The Q-system quantifies the engineering characteristics and stability of rockmasses through multi-parameter coupling analysis, providing a scientific basis for decision-making in underground engineering. Addressing Hong Kong's mountainous terrain and competent rock geology, the project employed the Rock Reinforcement Approach (RRA), integrating rock bolts and shotcrete to form a synergistic support system. Support design was optimized during construction through dynamic Q-value verification and 3D numerical modeling. This approach successfully enabled the excavation of the 36,2-meter super-large span cavern, demonstrating the applicability of the Q-system in composite hard-rock/fractured-rock strata.

Keywords: Q-system; Rock Reinforcement Approach; Cavern engineering; Construction design; Construction management

1. COMMENTS: BACKGROUND:

In land-scarce Hong Kong, the future of development lies underground. Picture a city where every inch of land is precious, yet beneath its hilly terrain and robust rock formations lies untapped potential. Over the years, cavern engineering has evolved from hosting nuisance facilities to becoming a cornerstone of sustainable development. The Hong Kong Government has embraced this vision, introducing a territory-wide Cavern Master Plan and expanding land-use guidelines to unlock the full potential of these hidden spaces. By relocating facilities like sewage treatment plants into caverns, surface land is freed for vital uses such as housing and commerce. This approach not only mitigates community nuisances but also transforms underutilized spaces into opportunities for growth. Innovations in construction, such as vibration-resistant concrete and digital rock analysis, are fast-tracking these projects while ensuring cost-effectiveness. Cavern development also addresses the city’s acute land shortage by providing cost-effective, land-intensive spaces for public and private uses without further land encroachment. This underground approach represents a paradigm shift from traditional two-dimensional planning to a forward-looking, multi-dimensional strategy. Through strategic studies and implementation of enabling measures, Hong Kong is leveraging its geological strengths to deliver innovative, sustainable solutions for urban expansion.

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2. HIGHLIGHT CAVERN INFORMATION:

The project includes the Relocation of public works to caverns. North cavern is drained structure, with excavation span 36.20m x excavation height 28.29m. The cross-section dimension is constant along its entire 79.6m length. South cavern is drained structure, with varying excavation span 33.20m x excavation height 27.89m. The excavation span is 34.2m wide for first 20m length of cavern and 33.2m wide for the remaining length of cavern. Adit is drained structure, with excavation span 12.20m x excavation height 9.94m. The cross-section dimension of Adit is constant along its entire 30.8m length.

3. INNOVATION POINS:

1. Construction Challenges and Information:
a. Probing: Utilize advanced probing to assess rock cover, quality, and groundwater inflow, ensuring accurate geological evaluations.
b. Grouting: Implement pre-excavation grouting if water inflow exceeds contract limits to maintain structural integrity.
c. Excavation: Use drill-and-blast methods for top-heading excavation, prioritizing safety and efficiency.
d. Surface Assessment: After mucking and scaling, map the exposed surface; a qualified geologist will categorize rock support class and integrate permanent spot bolting for stabilization.
e. Support Systems: Employ permanent rock bolts and temporary shotcrete tailored to rock class to ensure stability during excavation.
f. Sequential Excavation: Follow up with middle and bottom bench excavations consistently.
g. Drainage and Waterproofing: Install drainage strips and apply a high-performance waterproofing membrane to manage water ingress effectively.
h. Structural Layers: Finish with permanent sprayed concrete and construct internal structures such as drainage layers and DfMA RC walls.

2. Design Challenges and Information:
Long-lasting Rockbolts: Permanent rockbolts are designed for a lifespan of 100 years, incorporating double corrosion protection for durability in all permanent structures.
a. Temporary Support Strategy: Permanent sprayed concrete is not used for temporary rock support due to integrity concerns after nearby blasting. Instead, separate temporary sprayed concrete stabilizes excavations.
b. Rock Quality Assessment: Utilizes the Generalized Hoek-Brown Strength Criterion to derive Q-values. Two assessment systems are employed. The Q-System is for rock mass quality. The RMR is for advance length and stand-up time evaluations.
c. Kinematic Analysis for Stability: Main caverns and adits are excavated in competent rock, focusing on rock discontinuities. Kinematic analysis estimates potential rock wedges, informed by Borehole Televiewer Data and slope face mapping.
d. Rock Reinforcement Approach (RRA): In deep rock cover zones, a RRA is implemented, using permanent rockbolts to enable the rock to support the excavated ground efficiently.

3. Geotechnical Challenges:
Adverse geological structures, such as faults and joints, present significant challenges for deep underground projects under high in situ stresses, as they directly impact rock mass stability. While site selection typically aims to avoid large faults due to their fractured, loose, and poorly self-stabilizing nature, functional and layout constraints of underground caverns often make it unavoidable to encounter faults. In this project, two NW-SE trending faults have been identified, potentially causing adverse effects on the surrounding rock mass, including higher degrees of fracturing and weathering within the fault zone. Additionally, a NE-SW trending basaltic andesite/andesite dyke has been mapped, further complicating geological conditions. These factors highlight the importance of detailed geological assessments and mitigation strategies to ensure stability and safety in cavern development.

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