Implementation of Safety Management System in Deep Sewage Tunnels Construction Contracts under the Harbour Area Treatment Scheme, Stage I Project

Introduction

The Harbour Area Treatment Scheme (HATS) Stage I project (formerly called Strategic Sewage Disposal Scheme) undertaken by the Drainage Services Department (DSD) of the HKSAR Government involved, inter alia, construction of an underground sewage tunnel system spanning from east to west of the harbour area and 10 vertical shafts for the collection and conveyance of sewage in the harbour area to the sewage treatment works located at the Stonecutters for centralised treatment and disposal. The deep tunnels were 24 km in total length and of diameter ranging from 1.2 m to 3.5 m and depth ranging from 80 m to 145 m approximately. The diameter of vertical shafts connecting the surface sewerage systems and the underground tunnels were ranging from 2 m to 11 m.

In view of the size, complexity and high-risk nature of the HATS Stage I project, its construction work was carried out under three contracts, namely, Contract No. DC/96/17 (Harbour east section), DC/96/18 (central section) and DC/96/20 (west section) and the requirements for a SMS, in particular, the establishing of a SP and implementation of PFSS and ISAS, were incorporated into the contracts with a view to enhancing the promotion and monitoring the safety and health at work on construction sties. The following paragraphs will describe the safety and health hazards of the deep sewage tunnels construction and their control, together with the results of the implementation of the PFSS and ISAS in these contracts. Lastly, its effect on the site safety condition and the accident statistics of the three contracts will be discussed.

Hazards and Control during Construction

The majority of the tunnels were driven by tunnel boring machines (TBMs) supplemented by "drill and blast" method whilst the shafts were primarily sunk by conventional "drill and blast" method. Construction of tunnels and shafts, because of its underground nature and confined working environment, entailed much higher safety and health risks. These included, inter alia, collapse of excavated face, falls of rocks, seepage of ground water, faults zones and the presence of radon gas in fresh granite that were inherent with tunneling work; hazards generated by the use of explosive (dust, toxic nitrous fumes etc.), electrical tools (electric shock, fire etc.) and construction plants (TBM, grouting and drilling machines, etc.); and hazards due to the layout and configuration of the deep shaft-tunnel system (fall from height, poor natural ventilation, heat and humidity etc.). The confined working environment in the tunnels and limited accesses at ground surface not only imposed problems on construction but also increased the chance of workers being injured and the difficulty for escape and rescue in the event of emergency. It was therefore every risks had to be properly assessed and controlled by suitable safety precautionary measures.

In order to withhold excavated face of tunnels and shafts, "primary supports" in the form of steel arch ribs and laggings, rock bolts, rock dowels and sprayed concrete with or without steel wire mesh reinforcement as appropriate were installed in the tunnels to maintain the ground stability and safety of the opening[1]. "Primary supports" were erected as tunnel driving work or shaft sinking work proceeded and would be in place throughout the duration of construction. Whenever the tunnel driving work came to a stoppage, the contractor was required to erect "temporary supports" of steel or timber waling and strutting to protect the exposed ground. Temporary supports would be removed when driving work resumed. Finally, the as-driven lengths of tunnels were lined with either precast concrete segments or in-situ concrete as permanent finish and protection, whereas the vertical shafts were constructed to their design diameter by infilling the annular overbreak made during construction by concrete.

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Excessive seepage of groundwater would result in softening, loosening or even loss of ground and flooding problem. The TBM was equipped with two hydraulically operated rock drills mounted at the front for drilling of probe holes to investigate the ground ahead and to locate water sources. When excessive seepage was detected, the ground would be treated by grouting to reduce its inflow into the tunnel during driving. Other measures viz. channelling, pumping, piping and drainage were installed to alleviate the deterioration of excavated surfaces and maintain a dry working environment. Emergency fuel-driven generators were provided at each vertical shafts to operate the pumps for protection of the tunnels against flooding in the event of power blackout. Intercepting works such as kerbs and channels were installed on ground surface around the vertical shaft openings to prevent surface water from entering the as-driven tunnels.

The blasting operations and the supply, transportation, storage, use and disposal of explosive were under stringent statutory restrictions2 as imposed by the Commissioner of Mines of the HKSAR Government. The contractor and his blasting operator had to obtain the necessary licences and permits. No explosives and detonators other than those necessary for immediate use were allowed to be taken into the tunnels and shafts. Before blasting operation was to commence, the contractor was required to carry out "trial blasting" to demonstrate that the proposed method was safe; the resulting ground vibrations were within the acceptable limits and would not affect the safety and stability of the adjoining ground; and the specified tolerances for final surfaces could be achieved. Further, protective steel wire mesh screens properly weighed down with filled sandbags were erected to prevent the projection of flying fragments of material during blasting of the shafts.

Forced ventilation was the most effective and practical means for fresh air supply and dilution of air-borne contaminants and explosive gases to ensure that the atmosphere inhaled by the workers was safe and would contain sufficient quantity of oxygen. It was also essential to dissipating the heat and humidity in underground working environment. Regular tests on the atmosphere inside the tunnels were carried out by means of multi-gas detectors at least once each day to ensure that the concentration of the explosive gases was not exceeding 10% of the lower explosive limits3 (LELs), and that concentration of other hazardous gases were kept below their occupational exposure limits4 (OELs). The ventilation ducting was fabricated from non-combustible material to minimise fire hazards. Any machine operated with petrol was strictly banned in tunnels.

The presence of respirable dust in the atmosphere was monitored by an instant "dust meter"5, supplemented by air sampling instrument and subsequent gravimetric analysis at regular intervals. The control of dust hazard mainly relied on the forced ventilation, water sprays applied on dust sources, and good work practice such as wetting of the rock drilling process. Suitable respiratory protective equipment (RPE) was provided to all workers. The radiation level was also monitored, particularly after blasting. Air samples were collected by means of a "radon collector"5 for subsequent analysis and the results were submitted to the Radiation Health Unit, Department of Health of the HKSAR Government, who would advise, if necessary, the specific ventilation requirements at the working face. The acceptable radon concentration level6 is limited to below 900 Bq/m3. All internal combustion engines operating in the tunnels were equipped with scrubbers to "wash" the exhaust before it was discharged into the atmosphere. Blasting fumes were suppressed/absorbed by spraying water on muckpiles after blasting.

Apart from gas monitoring and engineering control measures, all workers were provided with suitable personal protective equipment (PPE) including safety helmet, caplamp with two packs of batteries, a "self-rescuer" type breathing apparatus which was able to last 15 minutes for emergency escape purpose, protective clothings (overall, safety shoes, gloves, wellingtons and mackintosh), eye protectors, ear muffs or ear plugs, and reflective vest. Telephone communications were installed at strategic locations underground to facilitate contact with the designated control room at ground surface. All tunnel workers were required to attend safety training on the safety rules and procedures for underground work and the use of their PPE.

Gantry cranes with mancage were installed over major shaft openings for safe transport of the personnel from ground surface to the tunnel invert. Emergency escape catladder with safety hoop and intermediate landing was also provided at major shafts. A tally board was erected at the entrance to the vertical shafts at ground surface. Name tags of the workers or any authorised persons entering the shaft/tunnel would be affixed onto the tally board as a register so that in an event of emergency the number and whereabouts of the people were immediately known to facilitate evacuation and rescue. The contractor was also required to provide emergency lightings and portable fire extinguishers in the tunnels. Further, fire-drills and "familiarisation programme" with the Fire Services Department of the HKSAR Government were required to be performed on regular basis. First-aid stations were provided at suitable intervals along the tunnels and arrangement was made to ensure that there was always at least one trained first-aider amongst each underground team to take care the injured worker before he was sent to the ground surface.

Safety Management System (SMS) for Public Works Contracts

The requirement for establishing a SMS for PWP construction contracts for the better management and control of site safety-related matters was first introduced in 1996 through the "Pay for Safety Scheme7 (PFSS)". In the past, site safety was conventionally referred to in construction contracts as a part of the general obligations imposed upon the contractor by some all-embracing preliminaries or preambles. The contractor was deemed to have allowed in his bill rates for the cost of meeting such obligations including site safety8. The consequence was that when the bill rates were too competitive a contractor might cut the "safety cost" expediently. The spirit of the PFSS was to separate site safety from the realm of competitive tendering and payment would be disbursed to contractors for performing certain prescribed site safety duties as an incentive. At the same time, the "Independent Safety Audit Scheme9 (ISAS)" was also introduced to monitor the adequacy and implementation of the SMS in selected contracts.

A prescribed bill of quantities (BOQ) showing the safety duties and rates was incorporated in three deep sewage tunnels construction contracts. The duties included mainly the preparation of a Safety Plan (SP) and its regular updating, hiring of safety personnel (Registered Safety Officer10), establishing safety committees to oversee all site safety-related matters, weekly safety walk, provision of safety training and lastly independent safety audits to be conducted quarterly under the ISAS. All items were pre-priced so that they would not be subject to competitive tendering. In general, the total possible payment of all safety items would be set approximately at 2% of the estimated value of the contract, excluding contingency sum or any sum for payment of fluctuation.

The objective of the ISAS was to conduct independent safety audits to check the adequacy of : Part (a) – the safety management system (i.e. SP, safety procedures, risk assessments, record keeping etc.) and Part (b) – its implementation on site (i.e. site safety conditions, compliance with safety procedures as laid down in the SP, safety training of workers etc.). Auditing was conducted on the basis of the "Works Bureau Safety Auditing System9 (WBSAS)" developed from a well-known British proprietary system called "The Construction CHASE11". The contractor would be entitled for a "bonus" payment in accordance with the BOQ for scoring 70% or above in both Part (a) and (b) of an audit as an incentive for his upkeeping of the SMS and site safety conditions. No payment would be granted if the score in either part was below 70%. Further, if the score in either part was below 60%, the "Report on Contractor's Performance12 (RCP)" of the respective quarter would be graded "Adverse" automatically, which was a severe penalty to a contractor as it might affect the future tendering opportunity of a contractor.

Safety Plan of Deep Sewage Tunnels Construction Contracts

Safety Plan (SP) formed the core of the SMS of a construction contract. The SP required for the three deep sewage tunnel construction contracts consisted of 14 elements as below :-

1. safety policy – a policy statement setting out the contractor's approach and commitment to maintain site safety and health,

2. safety organization – the organizational structure of safety personnel of the contractor,

3. safety and health training – procedures established to ensure that all workforce on site were given proper safety training,

4. safety rules and regulations – arrangements for communication and enforcement of general and specific safety rules (e.g. permit-to-work),

5. safety committees – arrangement for the monthly "Site Safety Management Committee (SSMC) Meeting" and "Site Safety Committee (SSC) Meeting" for monitoring and review of all site safety matters,

6. safety and health inspections – arrangements for identification, recording, reporting and rectification of on-site unsafe acts and unsafe conditions,

7. job hazards analysis – arrangements for identification and assessment of potential hazards and development of control measures,

8. personal protective equipment (PPE) – identification and selection of suitable PPE, issuing and record of maintenance,

9. accident investigation – procedures for prompt reporting and investigation of accidents and promulgation of findings and recommendations,

10. emergency preparedness – procedures to handle emergency situations on site including reporting, evacuation, rescue, drills and exercises etc.,

11. safety promotion – method of promoting and maintaining safety awareness of the workforce, e.g. safety campaigns, newsletters etc.,

12. health assurance programme – pre-job and regular medical examinations for workers liable to expose to health hazards and regular monitoring,

13. evaluation, selection and control of subcontractors – arrangement to ensure that only subcontractors with satisfactory safety performance would be hired, and

14. process control programme – arrangement for the effective on-site implementation of the safety working procedures, method statements and permit-to-work systems as laid down in the SP.

The safety audits under the ISAS were carried out on the basis of the SP. Part (a) of the audits referred to the auditing of elements No. (1) to (13) of the SP, i.e. the adequacy of the SMS whilst Part (b) referred to element No. (14), i.e. its enforcement on site.

Results of PFSS and ISAS in Deep Sewage Tunnels Construction Contracts

The three contracts (DC/96/17, DC/96/18 and DC/96/20), which had lasted for about 4 years, were all completed by December 2001. It was encouraging to note that no nonpayment of any of the safety BOQ items had ever been recorded throughout the course of these contracts. This implied that all contractors had performed the safety BOQ items satisfactorily and were reimbursed in accordance with the PFSS provisions in the respective contracts.

Regarding the results of the ISAS, it was also encouraging to note that all but one of the 44 independent safety audits conducted for the three contracts had passed 70% and the contractors were granted "bonus" payment in accordance with the respective contracts and no "Adverse" RCP had ever been given due to ISAS. Further, all three contracts have scored very high marks when compared with other DSD's contracts that were also subject to ISAS. The average scores of Part (a) and Part (b) were 83% and 81% respectively for Contract No. DC/96/17 out of 15 Nos. safety audits conducted; 84% and 85% for Contract No. DC/96/18 out of 13 Nos. safety audits conducted, and; 93% and 91% for Contract No. DC/96/20 out of 16 Nos. safety audits conducted. The high scores in Part (a) revealed that contractors had placed sufficient safety investments in establishing and maintaining the effectiveness of their SMS, whilst the high scores in Part (b) showed that the on-site enforcement of the safety procedures as laid down in the SP was adequate.

Effect on Site Safety Condition

With the establishment and implementation of SMS in the deep sewage tunnels construction contracts, the site safety condition as a whole had been promoted and was maintained at a satisfactory level. In particular, the following improvements were observed :

(a) all safety-related initiatives were able to be carried out in a systematic, accountable and controlled manner;

(b) sufficient resources and safety personnel were secured;

(c) all safety precautionary measures were correctly developed, implemented, monitored and recorded;

(d) site supervisory staff and construction workers have received safety training appropriate to their duties and responsibilities;

(e) accidents and nearmisses were investigated to identify probable causes so that corrective and preventive measures would be taken accordingly; and

(f) all safety matters were overseen by dedicated safety committees with involvement of top management.

Accident Statistics

Accident statistics are commonly taken as the safety performance indicator of a particular contract or contractor. Tunnelling contracts, because of the high risk nature, entail higher accident rates than other common civil works construction contracts and inevitably exceed the safety targets set for PWP construction contracts13. The accident statistics of the three deep sewage tunnels construction contracts were listed below against the safety targets.

Accidents Statistics of Deep Sewage Tunnels Construction Contracts						
Contract No.	Title	Nos. of Manhours Worked	Nos. of Reportable Accidents[1]	Nos. of Fatal Accidents[2]	Nos. of Dangerous Occurrences (DOs)[3]	Cumulative Accident Frequency Rate (CAFR)[4]
DC/96/17	Transfer System from Chai Wan to Kwun Tong and from Tseung Kwan O to Kwun Tong	3,521,607	91	2	2	2.58
DC/96/18	Transfer System from Kwun Tong to Stonecutters Island	2,713,459	67	1	1	2.47
DC/96/20	Transfer System from Kwai Chung to Stonecutters Island	1,941,718	56	0	0	2.88
Safety Targets set for PWP Construction Contracts				0	0	1.50

Notes :

1. Reportable accidents are accidents each of which resulting incapacity for more than 3 days.
2. Fatal accidents are accident each of which resulting in death.
3. DOs are incidents as defined in the First Schedule of Factories and Industrial Undertakings Regulations.
4. CAFR is expressed in the Nos. of reportable accidents per 100,000 manhours worked.

It can be seen that both Contract No. DC/96/17 and DC/96/18 have incurred one to two fatal accidents and dangerous occurrences. Further, the cumulative accident frequency rates (CAFRs), which were expressed in the Nos. of reportable accidents per 100,000 manhours worked, were ranging from a minimum of 2.47 to a maximum of 2.88. The accident statistics of the deep sewage tunnel contracts have no doubt exceeded the safety targets set for PWP construction contracts. However, when they were compared to those of two recent local rail-tunnel construction contracts of which the scope of work and size of contract were similar, the statistics were found to be in the same order in respects of the number of fatal accidents and dangerous occurrences, as well as the CAFRs.

Unlike rail tunnels that were constructed at shallow depth and had a much greater bore, the working environment inside the deep sewage tunnels was cramped and much more accident-prone. The layout and configuration of the deep shaft-tunnel system have made access much more difficult and dangerous. Further, the contractors were working in a very wet environment with significant seepage which has severely increased the risk at work. In conclusion, the safety performance of the deep sewage tunnels construction contracts were considered greatly improved as a result of the implementation of a SMS or otherwise the respective CAFRs would not have been suppressed to a comparable level as those of the rail-tunnel construction contracts.

Reference

[1] British Standard Institution BS EN 6164 : "Safety in Tunnelling in Construction Industry", BSI, 1990

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[3] British Standard Institution BS EN 50054 : "Electrical Apparatus for the Detection and Measurement of Combustible Gases", BSI, 1991

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[5] American Conference of Government Industrial Hygienists, Inc., "Air Sampling Instruments (for Evaluation of Atmosphere Contaminants)", ACGIH, Ohio, 1995

[6] Hong Kong Law Cap. 303, "Radiation Ordinance", HKSAR

[7] Works Bureau (formerly Works Branch), HKSAR Government, "Works Branch Technical

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[8] HKSAR Government (formerly Government of Hong Kong), "General Conditions of Contract for Civil Engineering Works", 1993

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[11] Health and Safety Technology and Management Ltd., "The Complete Health and Safety Evaluation Manual for the Construction Industry", London, 1990

[12] Works Bureau (formerly Works Branch), HKSAR Government, "Works Branch Technical Circular No. 12/96 – Report on Contractors' Performance – Guidance Notes for Completion of the Report", 1996

[13] Works Bureau (formerly Works Branch), HKSAR Government, "Construction Site Safety Manual", 1995