The End of Air Decompression Tables in Modern Compressed Air Work?

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Abstract

The Blackpool Air Decompression Table is inherent with decompression illness risk especially when working pressure over 2.5bar. In Hong Kong over the past fourteen years, French, Germany as well as German variance Oxygen decompression tables applied with care resulted in “near zero” decompression case and rate. The excessive heat stress in hot and humid tunnelling environment would be the most important risk factor which can violate the safety margin in oxygen decompression tables. Extra care should be considered in order to reach a zero Decompression illness case and rate if oxygen decompression table be employed. Blackpool Air Decompression Tables nowadays, may be reserved as a contingency when oxygen supply for decompression is in malfunction at below 2.5bar working pressure.

Keywords

Oxygen decompression table, Air-only Blackpool table, Decompression illness in compressed air work

Introduction

Modern Compressed Air Work in Hong Kong began in 1999 with the first EPB Tunnel Boring Machine employed in Kowloon-Canton Railway Corporation (KCRC) DB320 project. A tunnel boring machine (TBM) also known as a "mole", is a machine used to excavate tunnel with a circular cross section through a variety of soil and rock strata. They can bore through anything from hard rock to sand. Today, TBM can build tunnel diameter range from 6 to 21meter. Tunnel boring machines are used as an alternative to drilling and blasting (D&B) methods in rock and conventional "hand mining" in soil. TBMs have the advantages of limiting the disturbance to the surrounding ground and producing a smooth tunnel wall. This significantly reduces the cost of lining the tunnel, and makes them suitable to use in heavily urbanized areas.

There are two major tunnel boring machine employed in the tunnelling industry. EPB Shield TBM, a fast tunnelling technology with earth pressure support have a broad application range for soft & cohesive soils. So called Earth Pressure Balance Shields (EPB) turn the excavated material into a soil paste that is used as pliable, plastic support medium. This makes it possible to balance the pressure conditions at the tunnel face, avoids uncontrolled inflow of soil into the machine and creates the conditions for rapid tunnelling with minimum settlement. Mixshield TBM, an advance on conventional slurry technology with safe tunnelling technology for heterogeneous ground. The Mixshield technology provides support pressure in the excavation chamber is precisely managed using an automatically controlled air cushion. This means that heterogeneous geologies and high water pressures of more than 15 bar can be controlled safely even with very large excavation diameters.

Figure 1. Hong Kong first EPB TBM at 8.75m diameter built for KCRC in 1999 on project DB320

After compressed air work exposure, even with the modern TBM at shorter working hours, a safe decompression algorithm must be applied to reduce and

control decompression illness arise from breathing compressed air. Oxygen decompression tables developed and being applied in Europe since late ninety century. One of this table, the French Oxygen Decompression (Table – Mention D/O2), was first introduced to Hong Kong in 1999 during a mass transit railway project. Over nine hundred man-intervention with working pressure between 1.6 to 2.5bar resulted in "zero" case and rate of Decompression Illness (DCI). [1] With this experience, tunnel contractors continues to employ this oxygen decompression table at its highest working pressure at 4.2bar without any case of decompression illness in 2009. To have longer working time under high working pressure, a German Oxygen Decompression table variance also adopted at its highest working pressure at 4.2bar during the same project.

A French COMEX diving decompression table variance namely AirOxy12M Table and the original German Oxygen Decompression table also being applied in an ongoing Express Link (XRL) railway projects since 2010. This article described the detail result and the application of these few oxygen decompression tables and compared decompression illness case and rate with Air-only Blackpool Table within the Express Link railway projects.

Decompression illness records in twelve compressed air work tunnelling projects

In Hong Kong the first EPB Tunnel Boring Machine (TBM) employed in Kowloon-Canton Railway Corporation (KCRC) DB320 project in 1999. At the material time, oxygen decompression was a new technique and mostly afraid by layman on its fire risk and oxygen toxicity. With the adoption of clinical hyperbaric medicine safety standards and preventive measures such as controlling oxygen level below 23% and added air-break in every 25 minutes oxygen breathing, the project employed the French Oxygen Decompression for compressed air work (Table Mention D/O2) with 918 man-interventions resulted in "zero" case and rate of decompression illness.[1] Thereafter this first success of its application, tunnel contractors continued to employ the same French Oxygen Decompression Tables in several tunnel projects at varies working pressure. [2] The highest one completed in 2011 at 4.2bar with more than 172 man-interventions without any case of decompression illness. Within these seven completed TBM projects with oxygen for decompression, the total Decompression illness case were two and rate at 0.026%. Individual Decompression Illness rates at 0.13% and 0.21%.

As French Oxygen Decompression Table for compressed air work (Table Mention D/O2) is very conservative at its maximum working hours, therefore, a French COMEX diving table variance - Air/Oxy12M Table as well as the German Oxygen Decompression Table variance – Hamburg Table also introduced and

applied in Hong Kong in two higher working pressure tunnels. Detail summary as the following Table I.

Table I. Summary of Decompression illness in twelve TBM tunnelling projects in Hong Kong during 1999 to 2014

Project name & year of completion	**Number of Person exanimated for compressed air work (Fit/unfit case & ratio)**	**Decompression Table employed (maximum working pressure bar)**	**Decompression illness case (rate)**
KCRC West Rail DB320, *2000*	59/8 (7.35:1)	French Oxygen Decompression Table (2.7bar)	Zero case and rate in 918-man intervention
KCRC West Rail LDB-201, *2003*	135/20 (6.75:1)	French Oxygen Decompression Table (3.0bar)	Zero case and rate in 772 man-interventions
Link200JV on Kowloon Southern Link, *2007*	43/7 (6.1:1)	French Oxygen Decompression Table (1.9bar)	*One Type I DCI case in 474 man-intervention* ***(0.21%)***
DSD Contract DC/2007/16 on Lai Chi Kok Transfer Scheme – phase I, *2011*	53/11 (4.8:1)	French Oxygen Decompression Table (4.2bar)	Zero case and rate in 172 man-intervention
DSD Contract DC/2007/16 on Lai Chi Kok Transfer Scheme – phase II, *2011*		Hamburg Table (German Oxygen Table variance) (4.2bar)	Zero case and rate in 116 man-intervention
MTRC West Island Line 703 – TBM phase I, *2010*	102/33 (3.1:1)	French Oxygen Decompression Table (3.45bar)	Zero case and rate in 980 man-intervention
MTRC West Island Line 703 – TDM* phase II, *2011*		French Oxygen Decompression Table (2.9bar)	*One Type II DCI case in 741 man-intervention* ***(0.13%)***
MTRC ExpressLink Project XRL820, *2014*	123/33 (3.72:1)	Air/Oxy12M Decompression Table (French COMEX diving oxygen decompression table variance) (3.6bar)	One peripheral nerve DCI in 5524 man-intervention (0.019%) 842 man-intervention over 3.45bar
MTRC ExpressLink Project XRL823A, *ongoing*	92/35 (2.6:1)	French Oxygen Decompression Table (2.0bar)	Zero case and rate in 3602 man-interventions
MTRC ExpressLink Project XRL825 – phase I, *2012*	44/35 (1.25:1)	Air Decompression Table (3.2bar)	13 DCI case 1638 man-intervention (0.79%)
MTRC ExpressLink Project XRL825 – phase II, *ongoing*		German Oxygen Decompression Table (3.2bar)	Zero case and rate in 1682 man-intervention
Kai Tak	41/4	Air Decompression	Zero case and

Transfer Scheme, *2004*	(10.2:1)	Table (1.8bar)	rate in 82 man-interventions
Tuen Mun CLPP cable tunnel project, *2004*	27/2 (13.5:1)	Air Decompression Table (2.15bar)	Zero case and rate in 207 man-interventions
Project H2140, *2005*	29/4 (7.25:1)	Air Decompression Table (1.8bar)	Zero case and rate in 180 man-interventions

*TDM – Tunnel Dismantling Machine, the first in the world to dismantle an old TBM wall lining segments.

Compressed air work regulations in Hong Kong required the use of Air-only Blackpool Table as a standard. [3] The deployment of oxygen decompression table requires approval from relevant government departments as well as contractors' experience, expertise and economic support for its successful application.

Therefore, this Air-only Blackpool Table were still be employed in few short and swallow tunnels without any decompression illness case. Until the recent ExpressLink (XRL) project, one of the contractor decided to employ Air-only Blackpool Table up to 3.2bar working pressure resulted in 13 cases of DCI in 1638 man-interventions. Decompression Illness rate (DCI rate) at 0.798%, the highest DCI case and rate in the last fourteen years history in Hong Kong. Reviewed causative factors for these thirteen DCI cases as longer working hours over two and higher working pressure over 2.0bar. The DCI rate is compatible with well-known data in Air-only Blackpool Table on its application in U.K. for the past thirty years. [4] Detail as the following Table II.

Working Pressure Against DCI cases	0.0 to 1.0 bar	1.0 to 2.0 bar	2.0 to 3.0 bar	3.0 to 3.3 bar	Total
Total no. of worker enter	0	21	1356	261	1638
Total no. of DCI cases	0	0	11	2	13
DCI Rate (%)	0.00	0.00	0.81	0.77	0.79

Working time Against DCI cases	0 - 1 Hour	1 - 2 Hour	2 - 3 Hour	3 - 4 Hour	Total
Total no of worker enter	131	368	1031	108	1638
Total no of DCI cases	0	1	8	4	13
DCI Rate (%)	0.00	0.27	0.78	3.70	0.79

As this DCI case record, this contractor finally adopted the German Oxygen Decompression on its second phase with same working profile resulted in "zero" DCI up to the date of this article being summited.

What are the major difference between Compressed Air Work under mining and Compressed Air Work with Tunnel Boring Machine?

There are several fundamental difference between modern TBM compressed air work and traditional compressed air work in mining for tunnel. In conventional mining for tunnel, a large number of manpower and labour task required to work in compressed air with much longer working time under compressed air environment. Therefore, DCI case and rate was much higher in conventional mining compressed air work. The residue or late complication of compressed air work as dysbaric osteonecrosis was therefore more common and almost unavoidable in conventional mining tunnelling. The following Table III, lists the major characteristic and difference between conventional mining and modern TBM tunnelling.

Table III. Comparison on compressed air work with TBM and traditional mining for tunnelling

Method of Tunnel construction under Compressed Air Environment	Compressed Air Work in mining	Compressed Air Work in TBM
(1) Man power requirement in mining labour	A large number labour required (e.g. MTR Hong Kong Line in 1978, *near Seven hundred person engaged* in compressed air work)	A small number of labour required (e.g. DB320 project, only *Forty to Fifty person engaged* in compressed air work)
(2) Working time under compressed air environment	6~8 hour per day	2~3 hour per day
(3) Principle of applied Safety measures	Concepts from conventional mining industry	Plus clinical diving & *hyperbaric medicine*
(4) Working environment	Noise exposure, underground temperature & humidity varies and less likely to be controlled by administrative measures	Less varies and controllable with administrative measures

Reviewed advantages on decompression with Oxygen Decompression Tables

From the years of supporting tunnel projects experience, the author reviewed that oxygen decompression tables are very safe and almost DCI free if implemented with proper schedule especially in a conservative decompression algorithm as in French Oxygen Decompression Table. While in Hong Kong, as oxygen decompression tables applied in modern tunnelling, the DCI case and rate is much lower than the era on Air-only decompression table. As the compressed air regulations in Hong Kong still require compressed air workers have regular joint x-ray examination, therefore, all followed workers in the last fourteen year reviewed to have free from dysbaric osteonecrosis. It can reported as a way to avoid long term bone dysbarism of dysbaric necrosis. [5,6] Violation factors resulted in decompression illness with French Oxygen Decompression Table includes climbing exercise during bend-watch period and excessive heat stress in a Tunnel Dismantling Machine (TDM) project with highest recorded wet-bulb temperature at 40.5 degree under 2.8bar working pressure.

Medical Supervision and certification

In medical field, there is no rigid principle of certify a worker to be fit or unfit to work in compressed air environment. Guidelines and medical standards from known diving and compressed air work industry therefore be applied accordingly. In early 80s, Medical Code of Practice for Work in Compressed Air (Construction Industry Research and Information Association) was employed. [7] There were list of disqualication criteria including asthma, aseptic necrosis of bone, chronic middle ear infection, chronic lung diseases, diabetes, hernia, hypertension and others. Below Table IV, summarized the core medical examination and surveillance requirement for

compressed air work with Air-only Decompression Table.

Table IV. Summarize on the content and aim of medical examinations as specified in Compressed Air Regulations with Air-only Decompression Table

Types of medical examination	Content	Aim
Pre-placement	Comprehensive medical examination including Chest X-ray, ECG, joints X-ray, blood test and urine test	Excludes all pre-existing medical disqualifying criteria
Regular (every three or monthly)	Reviews on past month physical and medical fitness, any problem or disease arise during this period, any under reported Decompression Illness	Monitor and excludes newly developed medical problem such as hypertension, ear infection and risk of ear barotrauma
Annual	With joints X-ray examination	Excludes aseptic necrosis of bone

In early 80s, lung disease such as tuberculosis and chronic chest infection are still common in Hong Kong. Therefore, a chest X-ray examination alone could exclude about 30%~50% worker to be unfit to work in compressed air environment during their initial/pre-placement medical examination. [8] When Air-only Blackpool Table be employed on TBM tunnelling, even the most fitness workers are selected for work but it cleanly just palliative to decompression illness case and rate as shown in a recent ExpressLink project XRL825 phase I. In the era of Air-only Blackpool Table, there is a process to arrange workers stepwise increase in exposure time under compressed air work environment which known as acclimatization. It belief that this stepwise increase in exposure time may reduce decompression illness risk. However, as medical knowledge and research on using oxygen in decompression, the above acclimatization process had been removed in those countries with Decompression Tables on pure oxygen including France and Germany since the century of 1990. [2,9] To certifying an individual to be fit to work in compressed air environment at least it mean that there would be no expected or known risk in his or her body when he or she is exposed to compressed air environment. While as a responsible physician carrying out this medical examination, we must adjust or amend in line with the progress of new or updated guidelines [9,10] and medical standards.

Conclusion

To reduce Decompression Illness and its risk in related to compressed air work, scientists and diving physiologists employed the decompression table validation process including bubble dynamic and tissue mathematical modeling, animal trial and site human validation. [11] The application of pure oxygen in decompression for compressed air work goes through this decompression table validation process and it is one of the major advance in decompression illness control measure development in the past twenty years. Current French and Germany Compressed Air Work Decompression Tables are two of them which have been applied well both in their own countries, in Hong Kong, Australia and U.K. Nowadays, Air-only Decompression Tables should be reserved as a backup table for contingency when oxygen supply in shortage as in U.K. and all other countries with oxygen decompression tables for compressed air work.

The author concludes that with these oxygen decompression tables in compressed air work and in associated with a proper work methodology in compressed air work includes proper training and state of art medical surveillance scheme, Decompression Illness should be fully manageable and controllable to

provide a safer and better working environment to our valuable compressed air workforce in tunneling especially when Asia is growing with large a number of tunnels construction in this century.

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