“OCCUPATIONAL HEALTH AND SAFETY HAZARD IDENTIFICATION, RISK ASSESSMENT, DETERMINING CONTROLS: CASE STUDY ON CUT-AND-COVER UNDERGROUND STATIONS AND TUNNEL CONSTRUCTION"

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

CUMHUR CEYHAN

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

FEBRUARY 2012

Approval of the thesis:

OCCUPATIONAL HEALTH AND SAFETY HAZARD IDENTIFICATION, RISK ASSESSMENT, DETERMINING CONTROLS: CASE STUDY ON CUT AND COVER UNDERGROUND STATIONS AND TUNNEL CONSTRUCTION

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ABSTRACT

OCCUPATIONAL HEALTH AND SAFETY
HAZARD IDENTIFICATION, RISK ASSESSMENT, DETERMINING CONTROLS:
CASE STUDY ON
CUT AND COVER UNDERGROUND STATIONS AND TUNNEL CONSTRUCTION

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February 2012, 194 pages

The purpose of this thesis is to examine the hazard identification, risk assessment and related determining controls aspects of occupational health and safety topic, within the framework of a safety management system, for the construction industry. To achieve this purpose, a literature survey is carried out with specific emphasis on the standards, guidelines, codes of practices and other documents published by authorized institutions and national legislation related with the subject.

The Marmaray Project, which is considered as one of the major transportation infrastructure projects in Turkey, is chosen as the case study area. In the Marmaray Project, the case study is carried out at Üsküdar Underground Station Construction Site as an example for the cut and cover underground station construction and at Yedikule Tunnel Construction Site for the tunnel construction and achieved results are assessed within the context of this thesis.

Keywords: Hazard Identification, Risks Assessment, Determining Controls, Occupational Health and Safety Management System

ÖZ

İŞ GÜVENLİĞİ VE SAĞLIĞI KAPSAMINDA
TEHLİKELERİN TANIMLAMASI, RİSKLERİN DEĞERLENDİRMESİ VE
KONTROLLERİN BELİRLENMESİ AÇISINDAN ;
AÇ-KAPA YERALTI İSTASYONLARI VE TÜNEL İNŞAATI ÜZERİNE
YAPILAN BİR SAHA ÇALIŞMASI

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Tez Yöneticisi: Prof. Dr. M. Talat Birgönül

Şubat 2012, 194 sayfa

Bu tezin amacı inşaat sektöründe, iş güvenliği ve sağlığı yönetim sistemi çerçevesinde, iş güvenliği ve sağlığı ile ilgili olarak tehlike tanımlaması, risk değerlendirmesi ve kontrollerin belirlenmesi konularında bir çalışma gerçekleştirmek ve bu konuda yapılan uygulamaları bir saha çalışması ile ilgili kişilerin bilgisine kazandırmaktır. Bu amaca yönelik olarak; öncelikle konu ile ilgili standartlar, uygulama kuralları, uygulama kılavuzları ve yetkili kurumlarca basılmış dokümanlar ve ulusal yasal çerçeve başta olmak üzere bir literatür çalışması yapılmıştır. Saha çalışması alanı olarak Türkiye'nin en büyük ulaşım altyapı projelerinden biri olan Marmaray Projesi seçilmiştir. Marmaray projesinde yapılan incelemeler; aç–kapa yeraltı istasyonları inşaatına örnek olarak Üsküdar Yeraltı İstasyon Şantiyesinde, tünel inşaatına örnek olarak da Yedikule Tünel Şantiyesinde gerçekleştirilmiş ve elde edilen sonuçlar tez kapsamında değerlendirilmiştir.

Anahtar Kelimeler: Tehlike Tanımlaması, Risk Değerlendirmesi, Kontrollerin Belirlenmesi, İş Güvenliği ve Sağlığı Yönetim Sistemi

To My Beloved Selfless Mother & My Beloved Family…

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to my supervisor Prof. Dr. M. Talat Birgönül for his guidance and insight and patience throughout my study.

I would like to express my sincere appreciation to Assoc. Prof. Dr. Murat Gündüz for his helps in supplying current issues of British Standards, Occupational Health and Safety Series-Occupational health and safety management systems-Requirements and Guidelines.

I would like to sincerely thank to my dear friend Bülent Erdoğan, who is member of Board of Directors of Nurol Corporation, pursuing and encouraging me all along my study.

I would like to sincerely thank to my dear friend Nureddin Demir, who is project manager of the Marmaray Project CST Works and the real owner and designer of OH&S management system establishment studied in this thesis, for his hospitability in his construction site and motivating his staff to work nearly with me.

I would like to thank to Engin Yaman, Banu Tuna, Cenk Ergi and Mustafa Çetiner, who are supplying to me the documents patiently for my case study and spending their time for me in spite of their hard work, for their precious helps.

I would like to thank to dear Seçil Binboğa and my dear sister Sevgi Arıkan for their valuable helps in editing.

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LIST OF ABBREVIATIONS

ABI	:	The Association of British Insurers
ACC	:	Accident / or Acceptable
ACCEPT	:	Acceptable
ALARP	:	As Low As Reasonably Practicable
APM	:	Assistant Project Manager
ARCH	:	Archeological Explorations (Hazard)
BE	:	Built Environment
BS	:	British Standard
BSI	:	British Standard Institute
BTS	:	The British Tunneling Society
C	:	Cost
CDM	:	Construction and Design Management
CHEMIC	:	Work with Chemical (Hazard)
CIQP	:	Construction and Installation Quality Plan
COMP	:	Compressed Air (Hazard)
CONF	:	Confined Space (Hazard)
CONSD	:	Considerable
CONST	:	Construction
CST	:	Cut-and-Cover Stations and Tunnel Construction
DAFWC	:	Day Away from Work Case
DESC	:	Description
DIVE	:	Diving (Hazard)
DLH	:	General Directorate of Railways, Harbours, and Airports
DMLISH	:	Demolition (Hazard)
DSG	:	Design
E	:	Environment
EARTH	:	Earthworks (Hazard)
ELECT	:	Electrical Works (Hazard)
EMP	:	Employer
EPB	:	Earth Pressure Balance
EQ	:	Equipment
EQUIP	:	Construction equipment (Hazard)

ER	:	Employer Representative
ETA	:	Event Tree Analysis
EXT	:	External
F	:	Fatality
FMEA	:	Failure Mode and Effects Analysis
FMECA	:	Failure Mode, Effects & Criticality Analysis
FREQ	:	Frequency
FTA	:	Fault Tree Analysis
GN	:	Gama-Nurol Organization
H	:	Health
HAZID	:	Hazard Identification Workshop
HAZOP	:	Hazard and Operability Studies
HGHT	:	Work at Height (Hazard)
HOTW	:	Hotwork (Hazard)
HSE	:	Health and Safety Executive
HSE	:	Health, Safety and Environment
HSG	:	Health and Safety Guide
HUM	:	Human
ILO	:	International Labor Organization
ILO-OHS	:	International Labor Organization Occupational Health and Safety
INSIG	:	Insignificant
ITA	:	International Tunneling Association
JSA	:	Job Safety Analysis
JV	:	Joint Venture
LIFT	:	Lifting (Hazard)
LTI	:	Lost Time Injury
MACH	:	Moving Machinery (Hazard)
MANUAL	:	Manual Handling (Hazard)
MAT	:	Material
MS	:	Method Statement
MTO	:	Medical Treatment Only
NATM	:	New Austrian Tunneling Method
NCR	:	Non-conformities
OCC	:	Occasional
OH&S MS	:	Occupational Health and Safety Management System

OH&S	:	Occupational Health and Safety
OHSAS	:	Occupational Health and Safety Assessment Series
PHA	:	Preliminary Hazard Analysis
PI	:	Permanent Incapacity
PM	:	Project Management
PPE	:	Personal Protective Equipment
PRA	:	Preliminary Risk Analysis
PRESS	:	Pressure Vessel (Hazard)
Q	:	Quality
QA	:	Quality Assurance
QC	:	Quality Control
QHSE	:	Quality, Health & Safety and Environment
RADIA	:	Radiographic Works (Hazard)
RAT	:	Rating
RC	:	Reinforced Concrete
RWTC	:	Restricted Work/Transfer Case
S	:	Safety
SHFT	:	Shaft
SPME	:	Specified Powered Mechanical Equipment
T	:	Time
TBM	:	Tunnel Boring Machine
TGN	:	Taisei-Gama-Nurol Organization
TOOL	:	Tools (Hazard)
TRANS	:	Transportation (Hazard)
TRFC	:	Road Traffic (Hazard)
TS	:	Turkish Standards
TUNN	:	TBM/Tunneling (Hazard)
UK	:	United Kingdom
UNLIKE	:	Unlikely
UNWANT	:	Unwanted
V.UNLIKE	:	Very Unlikely
WVE	:	Work Verification Engineer

CHAPTER 1

INTRODUCTION

Today, together with the growth and improvement of the industry, the size of the constructions has got enormous and much more complex than ever before.

This, of course, has brought up huge construction organizations and high construction technologies together. As the construction durations become shorter, the speed and intensity of works have extremely increased. Technological changes have introduced new hazard types.

All those have created enough reasons and conditions for the work accidents and ill health to be risen up. Of course, in many countries, authorities described heavy health and safety laws and regulations corresponding to the new situations.

But in time, it is clearly understood that the hard laws or regulations alone were not enough to decrease work accidents, in other words, to provide safe and healthy construction sites.

The risk assessment concept is created just under such an occupational health and safety climate. In fact, in health and safety understanding, the central position of the worker is replaced by the occupation. It is understood that health and safety matter is not alone a law's or regulation's or worker's matter but a matter directly related with organization and management. This understanding carried competent people to follow the risk assessment and risk control processes in an effective occupational health and management system. The further step was the integration of the occupational health and safety management system with the others, such as quality, environmental, security or financial management systems. Now, occupational health and safety management system is described and designed by every interested party as an integrated part of a whole management system of an organization which includes quality, environment etc.

As the necessity of new approach, laws and regulations related with OH&S are rearranged in many countries. Additionally, relevant standards, guides and codes of practices are developed by authorities about what are the requirements of an effective occupational health and safety management system and how it is possible

to establish, maintain and improve it successfully as part of an overall management system at a workplace.

Today, OH&S has become an aspect that is nearly followed by media and is interested by many different parties such as the community, authority, owners, employers, employees, contractors, insurers, customers, suppliers, clients etc.,

TGN Organization, the contractor of Contract BC1 in the Marmaray Project which is chosen as the site for the case study, established its OH&S management system in compliance with the applicable National Legislation, BS-OHSAS 18001 "Occupational Health and Safety Series-Occupational health and safety management systems-Requirements", BS-OHSAS 18002 "Occupational Health and Safety Series-Occupational health and safety management systems-Guidelines for the implementation of OHSAS 18001", CDM-Construction (Design and Management) Regulations, BS 6164 "Code of practice for safety in tunneling in the construction industry".

So in this study, it is mainly based on those references for general approaches and requirements particularly for a successful OH&S management system establishment and what they require about hazard identification, risk assessment and risk controls processes which is the subject of the study.

On the other hand, since they are nearly interrelated with the above standards, guides or regulations; OHSAS 18001:2007 itself, recommends to ought to be read in conjunction with BS 8800 and HSG65; it is also worked on the references: BS 8800:2004 "Occupational health and safety management systems – Guide", The Health and Safety Executive's Booklet HSG 65:1997(Second Edition) "Successful health and safety management", and ILO-OHS:2001 "Guidelines on occupational safety and health management systems", where they are considerable.

In this respect, International Tunneling Association (ITA), Working Group No.2:2004 "Guidelines for tunneling risk management" and ABI (The Association of British Insurers) and BTS (The British Tunneling Society): 2003 "The joint code of practice for risk management of tunnel works in the UK" are other utilized references for tunneling works besides BS 6164:2001.

"OH&S management system" is part of an organization's management system used to develop and implement its OH&S policy and manage its OH&S risks, which is a set of interrelated elements used to establish policy and objectives and to achieve

those objectives. An organization together with its OH&S management system minimizes risk to employees and others, improves business performance and establishes a responsible image within the marketplace. According to National Legislation, Work Law No:4857, Clause 77/1; the employer is the liable party for taking all precautions to ensure OH&S in workplaces and to supply all necessary tools and equipments. An OH&S management system takes all preventive and corrective actions before any hazardous source, situation or act causes any incident in which an injury or ill health or fatality occurred, or could have occurred. It means an OH&S management system is proactive rather than reactive. The success of an OH&S management system is closely dependent on human factors and the safety culture in the related organization.

OH&S management systems are executed on the base of methodology named as Plan-Do-Check-Act (PDCA). This methodology is applicable for all processes and compatible with the methodology, process approach, which ISO 9001 promotes. So OH&S management systems can be integrated without problem with other management systems in the organization such as quality or environment.

OH&S management system is a set of interconnected elements which are “initial review”, “OH&S policy”, “planning”, “implementation and operation”, “checking and corrective action”, “management review”. Hazard identification, risk assessment and determining controls processes are performed in the part of “planning” stage of the entire OH&S management system. “Planning” process is completed through additional “legal and other requirements” and “objectives and programmes” executions. OH&S policy and objectives, which are the commitments of top management, compose the organization’s requirements of OH&S management system. On the other hand, National Legislation and relevant standards, guides or codes of practice compose legal and other requirements.

“Hazard” is a source, situation, or an act with a potential for harm in terms of human injury or ill health, or a combination of these. It does not include the potential to cause damage to property, plant, products or the environment (OHSAS 18001:2007). Hazards can be physical, chemical, biological and psychological. Accordingly “hazard identification” is the process of recognizing that a hazard exists and defining its characteristics.

In the scope of hazard identification process, besides identifying hazards, the identification of existing control measures is also executed. The identified existing

control measures constitutes the base on which the frequency of hazardous event, severity of consequence of occurrence and hence risk value are assessed subsequent to hazard identification.

Hazard identification mainly requires an exhaustive work flow and activity analysis to reach the hazards which may possibly arise during execution any construction work. A hazard identification process considers any kind of work or activity, both routine and non-routine activities, and situations and sources; e.g. the activities such as equipment cleaning or non-scheduled maintenance, plant or equipment start-up or shut-down, extreme weather conditions, utility disruptions, visits to workplace, temporary arrangements etc. Incident reviews, safety tours and inspections, making observations of behavior and work practices; interviews, surveys and participation of people, past experience of the organization and experience of other organizations performed similar works compose the typical sources of information for hazard identification process. A multidisciplinary competent team is required to perform the overall hazard identification, risk assessment and determining controls process. So a hazard identification workshop (HAZID workshop) is needed to construct.

In HAZID workshop, work flow and activity analysis is performed by itemizing the works which have to be performed to realize the construction project, and then sub-itemizing in a chain order for deduction of hazard which is hazardous source, situation, act or a combination of these in definition. It is to say, in HAZID workshop, the steps of the construction are determined and hence main “works” are defined firstly, and then “main activities” required to perform each main work, and then the “activities” for each main activity. By the work flow and activity analysis, at the end, the hazard (process) arising from each class of work - each main activity - each activity which constitute a row of activity is identified. As an example for cut and cover underground stations construction; take “**work**” as “foundation base preparation”, then “**main activity**” is “earth work”, “**activity**” is “excavation” and deducted “**process(hazard)**” is “equipment”, finally “**workplace**” and “**equipment used**”, e.g. as “backhoe” are noted. This step composes a row of activity from which the identified hazard arises.

For the same “**work**” of “foundation base preparation”, there may be one or more “**main activity**”, e.g. “earth works”, “waterproofing”; and for the same “**main activity**” of ”earth works” or “water proofing”, there may be one or more “**activity**”, e.g. “excavation”, ”ground leveling”, “dewatering” for “earth works” and “membrane

installation" for "water proofing". In the same way from each "**activity**" may rise one or more "**process (hazard)**", e.g. "tools" and "electrical works" for "dewatering" and "manual handling" and "working at height" for "membrane installation".

Once the processes (hazards) are identified, subsequently a root cause analysis is executed for each process (hazard). There, "**initiating events**" and "**top events**" are predicted; "**sources of causes**" as human, material, equipment or external sources; and "**consequent risks**" such as fatality or injury etc. are determined for each identified hazard. For example for the "**process (hazard)**" of "electrical works", "**initiating events**" may be "lack of skill", "direct contact" or "arching" etc.; "**sources of causes**" may be due to all "human", "material", "equipment" or "external source"; "**top events**" may be "electrical shock" or "burn by arching"; finally "**consequent risks**" may be "fatality".

There are two main and different approaches for the definition of "incident" and "accident" terms between standards, guides and codes of practice. The first is the offer of OHSAS 18001:2007 which defines incident as work-related events in which an injury or ill health (regardless of severity) or fatality occurred, or could have occurred. So here an accident is accepted only an incident which has given rise to injury, ill health or fatality and an incident where no injury, ill health, or fatality occurs is referred as "near miss". The second approach is made by BS 8800:2004 which defines "accident" as undesired event giving rise to death, ill health, injury, while "incident" is referred as only an event where no injury, ill health, or fatality occurs.

Recordable injuries caused by work related accidents may be classified as "fatality (F)", "permanent incapacity (PI)", "restricted work/transfer case (RWTC)", "lost time injury (LTI)", "day away from work case (DAFWC)" and "medical treatment only (MTO)".

"Risk" is combination of the likelihood of an occurrence of a hazardous event or exposure and the severity of injury or ill health that can be caused by the event or exposure. Accordingly "risk assessment" is defined as process of evaluating the risk arising from a hazard, taking into account the adequacy of any existing controls, and deciding whether or not the risk is acceptable. This first fundamental approach is followed by OHSAS 18001:2007, and differentiate hazard identification, risk assessment and determining controls processes as separate executions. While BS 8800 offers another commonly used definition to risk assessment process which takes risk assessment as process of identifying hazards and evaluating the risks to

health and safety arising from these hazards taking account of the existing risk controls or, in the case of a new activity, the proposed risk controls. According to this second fundamental approach, the term of “risk assessment” covers “hazard identification”, “risk assessment” and “determining controls” processes as an entire process, on the contrary of the first approach. In application, it is observed that those two opposite approaches are used commonly in the same degree.

Risk assessment process is composed of mainly two parts which are estimating the risk values and deciding about the acceptability of the risk.

The estimation of risk values is, in fact, performed by through determination of “likelihood of harm” and “severity of consequence”. Here, the main point is that the rates for those items are evaluated on the base of the existing risk control measures. The organization may take the advantage of risk assessments previously developed for typical activities in different workplaces of other organizations.

There are qualitative or quantitative methodologies to estimate risk values. The organization has to choose the adequate methodology specific to its workplace, while it has the chance to vary the risk assessment method for a particular area of the workplace. The key issues, here, are the confidence in the mathematical model used for the quantitative techniques and completeness, consistency or correctness for the qualitative methodologies. However, in some countries, for complex process plants which may require complex mathematical calculations, it is specified by sector-specific legislation.

In the case study, risk assessment process is carried out by “5x5 risk matrix” methodology. It is a semi-quantitative method. Risk value (R) is estimated by multiplying likelihood of occurrence (P) and potential severity of harm (S) as (R = P x S). There are five categories for likelihood of harm which are “very likely”, “likely”, “occasional”, “unlikely”, ”very unlikely” and they take values from 5 to 1, respectively. In the same way, severity of consequence is, also, divided into five categories which are “disastrous”, “severe”, “serious”, “considerable”, “insignificant” and again they take values from 5 to 1, respectively. 5x5 risk matrix is established by using those five categories for likelihood of harm and severity of consequence. Risks established on the risk matrix are categorized on the base of risk values estimated, which are 1 to 10, 12, 15, 16, 20, 25. According to this categorization, risk categories are developed as “very high” having risk values of (15, 16, 20, 25),

“high” having risk values of (10,12), “medium” having risk values of (8, 9), “low” having risk values of (5, 6) and “very low” having risk values of (1, 2, 3, 4).

Second classification of risks are made on the base of risk acceptance. There are four categories in this meaning: “unacceptable”, “unwanted”, “acceptable” and “negligible”.

The correspondence of categories and their risk values can be summarized as:

- “unacceptable” risk corresponds to “very high” risk and covers risk values of (15, 16, 20, 25),
- “Unwanted” risk corresponds to “high”, “medium”, “low” risks and covers risk values of (5, 6, 8, 9,10,12),
- “acceptable” risk corresponds to ”very low” risk and covers risk values of (3, 4),
- “negligible” risk corresponds again to “very low” risk and covers risk values of (1, 2).

At the end, the risk assessment values are documented in a register with items of “frequency of occurrence”, “severity of consequence” in descriptive and quantitative values (e.g. likely and 4 – serious and 3, respectively); “risk value” (e.g. 6, 8, 12 etc.) and “risk class” on the base of risk acceptance (e.g. unacceptable, unwanted etc.). Hence it is decided about the risk whether it is acceptable or not.

Risk assessment process is repeated and risk levels are estimated once more by the same method of analysis for the conditions after mitigation and then it is checked whether the risk level is reduced to acceptable level or not.

Where the decision at the end of the risk assessment is in the way of that new or improved controls are required to bring risks to the acceptable level, a further process of “determining controls” should be carried out. This is the most important leg of process subsequent to hazard identification and risk assessment processes, because the final aim of all the assessments carried out by now, and of course, of overall OH&S management system, is just to provide a safe working workplace and minimize the risks of persons. Risk controls has a hierarchy in application which are “elimination” (e.g. modification of design), “substitution” (e.g. lowering the electrical voltage), “engineering controls” (e.g. installation of interlocking systems), “signage, warnings and administrative controls” (e.g. safety signs, preparing safety

procedures) and “personal protective equipment (PPE) (e.g. safety glasses). In choosing the appropriate option, relative cost, risk mitigation benefit and reliability of the options should be discussed. Actions maybe preventive to eliminate the cause of a potential nonconformity or corrective to prevent reoccurrence. Actions taken account to reduce the risk value or control the risk is prioritized between themselves for an effective mitigation application. In prioritizing the actions, their risk reduction benefits and the magnitude of the risk for which they are addressed are comprehensively evaluated. For an example of determining controls process, take “electrical works” as “**process (hazard)**”, then “**mitigation**” would be preparing “electrical safety procedure”, and then “**proposed actions**” in prioritized manner would be 1.Implement procedure, 2.Supervision, 3.Test/inspection of equipment 4.Regular maintenance, 5.Certified electrician, 6.Awareness. Finally by “**in charge**” topic “mitigation” and “proposed actions” are addressed.

At the end of hazard identification, risk assessment and determining controls processes, all of the results obtained for each process are documented in comprehensive “risk register” tables as a total. Those “risk registers” are the fundamental documents of overall OH&S management system and they are reviewed and continually improved throughout OH&S management.

For the case study performed in the thesis, the Marmaray Project is chosen as the case study area. It is considered one of the major transportation infrastructure project in Turkey. For the cut and cover underground station construction, Üsküdar Underground Station Construction Site and for the tunnel construction, Yedikule Tunnel Construction Site are preferred as the fields to carry out the case study. Üsküdar Underground Station construction is 278 m in length, 32 m in width, 30 m in depth under the sea level and it is just at the sea side. Yedikule Tunnel Construction is the tunnel construction between Yedikule-Yenikapı having 2x2480 m length and bored by closed-face shield TBM with earth pressure balance (EPB – TBM). The Employer is “General Directorate of Railways, Harbours, and Airports Construction”, the DLH; and the Contractor is the joint venture established by Taisei Corporation, the lead partner from Japan; Gama Endüstri Tesisleri İmalat Montaj A.Ş., from Turkey and Nurol İnşaat ve Ticaret A.Ş., from Turkey (TGN Organization). Üsküdar Underground Station construction and tunnel construction between Yedikule-Yenikapı (Yedikule Tunnel Construction Site) are executed by Gama Endüstri Tesisleri İmalat Montaj A.Ş and Nurol İnşaat ve Ticaret A.Ş together in accordance

with the allocation of constructions between the parties of the Joint Venture (GN Organization).

For the purpose of the thesis;

In Chapter 2, it is aimed to make clear, what should be understood from the terms used and what changes exist between the definitions of terms offered by different main standards, guides and codes of practice,

In Chapter 3, a literature survey is carried out on the Occupational Health & Safety (OH&S) and OH&S management systems in a limited part enough to enable to define the position of the subject of the study in overall OH&S management system with the specific emphasis on the standards, guidelines, codes of practice,

In Chapter 4, a comprehensive literature survey on hazard identification, risk assessment and determining control processes is carried out in the question of how a successful OH&S management system is developed, again, with the specific emphasis on the standards, guidelines, codes of practice, other documents published by authorized institutions and applicable National Legislation,

In Chapter 5, the case study is implemented. The case application about hazard identification, risk assessment and determining controls are presented in the tables as arranged in accordance the format of the thesis. In this meaning, the tables of “activity analysis and hazard identification”, “event analysis in the scope of hazard identification”, “risk assessment before mitigation”, “mitigation measures”, “risk assessment after mitigation” and “risk register” are prepared for both Üsküdar Underground Station Construction Site and Yedikule Tunnel Construction Site.

In Chapter 6, it is discussed on the results of the case study, tried to present the conclusions arrived and criticized the application. It is also discussed on the future researches and on the terminology used in literature.

CHAPTER 2

TERMS AND DEFINITIONS

In the study, terms and definitions offered by BS-OHSAS 18001:2007 are used and applied for all items and steps of an OH&S management system. Turkish Standards Institute also based on BS-OHSAS 18001:2007 as constituting TS 18001:2008 standard specifying the requirements for OH&S management systems. This fact encouraged us to come to the decision of preferring BS-OHSAS 18001:2007, its content and its terms, about OH&S management systems in the study.

The terms and definitions offered by other important standards, guides or codes of practice but differing from OHSAS 18001:2007 are also used time to time, if it provides easiness in understanding.

Here, the main terms and definitions offered by OHSAS 18001:2007 are noted down together with the different approaches by other main standards, guides, codes of practice just under it. The terms are ordered regarding their closeness to the subject of the study which is about hazard identification, risk assessment and determining controls. It is aimed here to make it clear, just at the beginning of the study, what should be understood from the terms used and what changes exist between the definitions of terms offered by different main standards, guides and codes of practice.

Hazard

Source, situation, or act with a potential for harm in terms of human injury or ill health, or a combination of these.

In HSG 65:1997, “hazard” definition includes the potential to cause damage to property, plant, products or the environment on the contrary of OHSAS 18001:2007, however BS8800:2004, ILO-OHS:2001 conform with OHSAS 18001:2007’s definition.

Hazard identification

Process of recognizing that a hazard exists and defining its characteristics.

Event

An occurrence or situation represented as a node in event and fault trees (e.g. gas leak, status of gas detection system etc.) (OH&S Manual of TGN Organization).

Incident

Work-related event(s) in which an injury or ill health (regardless of severity) or fatality occurred, or could have occurred (an emergency situation is also a particular type to incident).

“Incident” is defined as “hazardous event where no harm occurs” in BS 8800:2004. So it does not cover “accident” in definition on the contrary of OHSAS 18001:2007.

In ILO-OHS: 2001 and HSG 65:1997 “accident” and “incident” are defined discriminately, too, as events, which causes injury, ill health or fatality and causes no harm respectively.

Accident

An accident is an incident which has given rise to injury, ill health or fatality.

“Accident” is defined as “undesired event giving rise to death, ill health, injury” in BS 8800:2004. So it is not covered under the term of “incident” on the contrary of OHSAS 18001:2007.

In ILO-OHS: 2001 and HSG 65:1997 “accident” and “incident” are defined discriminately, too, as events, which causes injury, ill health or fatality and causes no harm respectively.

Near-miss

An incident where no injury, ill health, or fatality occurs may also be referred to as a “near-hit”, “close call” or “dangerous occurrence”.

This definition corresponds to definition of “incident” made in BS 8800:2004.

ill health

Identifiable, adverse physical or mental condition arising from and/or made worse by a work activity and/or work-related situation.

Risk

Combination of the likelihood of an occurrence of a hazardous event or exposure(s) and the severity of injury or ill health that can be caused by the event or exposure(s).

Risk assessment

Process of evaluating the risk(s) arising from a hazard(s), taking into account the adequacy of any existing controls, and deciding whether or not the risk(s) is acceptable.

Risk assessment is defined as " process of identifying hazards and evaluating the risks to health and safety arising from these hazards taking account of the existing risk controls(or, in the case of a new activity, the proposed risk controls) in BS 8800:2004. So hazard identification, risk assessment and determining controls processes which are defined each as a separate process in OHSAS 18001:2007, are collected under the term of "risk assessment" as a unique process in BS 8800:2004.

The terminology used in BS 6164:2004 "Codes of practice for safety in tunneling in the construction industry" mostly conforms with OHSAS 18001:2007 regarding hazard identification, risk assessment and determining controls.

The other reference regarded for tunneling works, ABI (The Association of British Insurers) and BTS (The British Tunneling Society) : 2003 The joint code of practice for risk management of tunnel works in the UK coincides with BS 8800:2004 completely in the definition of risk assessment, and accordingly gather hazard identification, risk assessment and determining controls processes under an unique term of "risk assessment".

On the other hand, for the definition of risk assessment; in Eskesen, S.D., Tengborg, P., Kampmann,J., Veicherts T.H. : 2004 Guidelines for tunneling risk management : International Tunneling Association (ITA), Working Group No.2; a third way is followed between OHSAS 18001:2007 and BS 8800:2004, so that it defines "risk analysis" (includes identification of hazards and description of risks as either qualitative or quantitative) and "risk evaluation" (comparison of the results of a risk analysis with risk acceptance criteria or other decision criteria) and combines them under the term of "risk assessment" and still holds "risk mitigation" as separate.

Acceptable risk

Risk that has been reduced to a level that can be tolerated by the organization having regard to its legal obligations and its own OH&S policy.

OHSAS 18001:2007 does not use the term of “tolerable risk” any more, instead of that, “acceptable risk” is replaced by “tolerable risk”. However BS 8800:2004 defines tolerable risk (risk at the level that can be accepted provided risk controls are implemented to reduce risk as low as is reasonably practicable i.e. reduced to the point where it can be shown that costs of further risk reduction would be disproportionate to the further benefits) additional to acceptable and unacceptable risks terms.

Corrective action

Action to eliminate the cause of a detected nonconformity (there can be more than one cause for a potential nonconformity-corrective action is taken to prevent reoccurrence whereas preventive action is taken to prevent occurrence).

Preventive action

Action to eliminate the cause of a potential nonconformity (there can be more than one cause for a potential nonconformity-preventive action is taken to prevent occurrence whereas corrective action is taken to prevent reoccurrence)

Mitigation

Measures taken to reduce the consequences of a potential hazardous event. Mitigation measures include: active systems (gas, fire, smoke alarms etc.) and passive systems (fire and blast walls, protective coating etc.) intended to detect and abate incidents and operational systems intended for emergency management (contingency plans, training etc.).

Nonconformity

Non fulfillment of a requirement (nonconformity can be any deviation from relevant standards, practices, procedures, legal requirements etc. and OH&S management system requirements).

As Low As Reasonably Practicable (ALARP)

To reduce a risk to a level which is as low as reasonably practicable involves balancing reduction in risk against the time, trouble, difficulty and cost of achieving it. This level represents the point, objectively assessed, at which the time, trouble, difficulty and cost of further reduction measures become unreasonably disproportionate to the additional risk reduction obtained (OH&S Manual of TGN Organization).

Occupational health and safety (OH&S)

Conditions and factors that affect, or could affect, the health and safety of employees or other workers (including temporary workers and contractor personnel), visitors, or any other person in the workplace (organizations can be subject to legal requirements for the health and safety of persons beyond the immediate workplace, or who are exposed to the workplace activities).

OH&S management system

Part of an organization's management system used to develop and implement its OH&S policy and manage its OH&S risks, which is a set of interrelated elements used to establish policy and objectives and to achieve those objectives.

OH&S policy

Overall intentions and direction of an organization related to its OH&S performance as formally expressed by top management (OH&S Policy provides a framework for action and for the setting of OH&S objectives).

OH&S objective

OH&S goal, in terms of OH&S performance that an organization sets itself to achieve (they should be consistent with the OH&S policy and should be quantified wherever practicable).

Organization

Company, corporation, firm, enterprise, authority, whether incorporated or not, public or private, that has its own functions and administration.

Workplace

Any physical location in which work related activities are performed under the control of the organization (a workplace, considering OH&S effects, covers the personnel who are, e.g. travelling or in transit (driving, flying, on boats or trains), working at the premises of a client or customer, or working at home).

Risk Register

ABI (The Association of British Insurers) and BTS (The British Tunneling Society) : 2003 The joint code of practice for risk management of tunnel works in the UK defines risk register as the document prepared subsequent the risk assessment process (defined as the overall process of hazard identification, risk assessment and determining controls) and included requirements of clarification of the ownership of risks, detailing clearly and concisely how the risks are to be allocated, controlled, mitigated and managed.

CHAPTER 3

OCCUPATIONAL HEALTH AND SAFETY (OH&S) AND OH&S MANAGEMENT SYSTEMS

3.1 General

In OHSAS 18001:2007, OH&S is defined as the conditions and factors related with the health and safety of employees or other workers in workplace. While temporary workers and contractor personnel is included in the scope of the OH&S; at the same time, visitors or any other person in the workplace accepted as part of OH&S. Meanwhile, the organizations are made aware by noting that they can be subject of legal requirements for the health and safety of the persons beyond the workplace, who are affected by workplace activities.

On the other hand OH&S management system, in OHSAS 18001:2007, is described as a management system of an organization which is integrated with the overall management system including quality and environment aspects and aimed to develop and implement organization's OH&S policy and objectives to control its OH&S risks. It is noted that a management system is, in fact, a set of interrelated elements for establishing and then achieving OH&S policy and objectives, which involves organizational structure, planning activities, resources, responsibilities, procedures, processes etc.

For a construction, OH&S duties and required planning studies begin just from pre-tender stage and continue through design, tendering stages until the end of construction phase. So, duties related with OH&S cover upon clients, designers, contractors and planning supervisors. Each party has his own requirements to comply regarding his role in the phases of the enterprise. (Construction (Design and Management) Regulations: 1994, Construction Information Sheets)

ILO-OHS: 2001 specifies that the employer has the responsibility &duty for OH&S and its compliance with OH&S requirements, national laws and regulations. For an OH&S management system, the links between the national framework and its essential elements are illustrated in Figure 3.1.

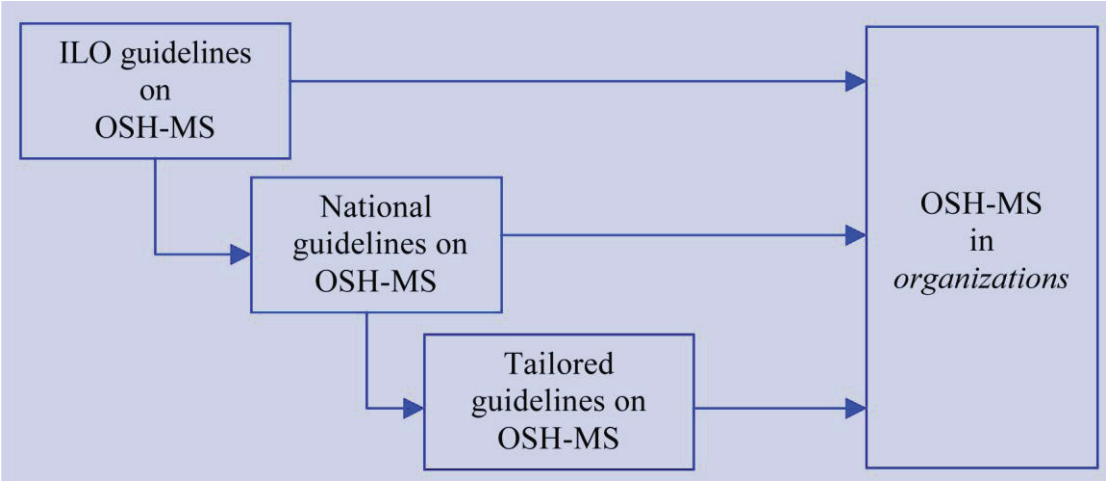


Figure 3.1 The elements of the national framework for OH&S management Systems (ILO-OHS: 2001, pg.4)

In the same way, according to Turkish national legislation, the employer is liable for taking all precautions to ensure OH&S in workplaces and to supply all necessary tools and equipments completely (Work Law No: 4857, Clause 77/1).

Besides the ethical and regulatory reasons, reducing work related accidents and ill health has the sound economic reasons. An OH&S management system integrated with the management systems of other aspects of business performance:

- Minimize risk to employees and others;
- Improve business performance, and
- Assist organizations to establish a responsible image within the marketplace (BS 8800:2004).

OH&S management system is not an independent or separate management body, on the contrary, it has an entirety in itself and also with the overall management system of the organization.

In many countries, legal requirements for OH&S are put a law in the force by national legislation to prevent and control the potentially harmful effects caused by workplace activities, both in workplace and beyond it. Any OH&S management systems ought to take into account those legal requirements in its each step such as establishing, implementation, maintaining and especially in the part of hazard identification, risk assessment and determination of control measures. Additionally, OH&S management systems should comply with the requirements

specified by relevant standards or guides to enable to control organization's OH&S risks and manage a continual performance improvement.

An OH&S management system should be developed and maintained in a proactive manner rather than reactive. In this respect, all actions and precautions to reduce the OH&S risks and hence to prevent damage or ill health should be determined before any hazardous conditions may come out or any hazardous events may occur. For this purpose, an OH&S management system should have the ability of providing participation of all persons at each level and function in the organization, and training them continuously to make aware about the hazardous acts, situations and sources all along the work.

As it is described in its definition, an OH&S management system is a set of interconnected elements. Addition to planning and implementing, it includes performance measurement and auditing processes to be able to assess its effectiveness at any time of work and a continuous feedback to the system regarding the results of those measurements together with the outcomes obtained by daily and periodical site inspections made by competent persons.

The level of detail and documentation and extent of resources supplied of an OH&S management system depend on mainly the scope of the system, nature of activities, organizational culture and the size of the organization. (OHSAS 18001:2008)

For the success of the OH&S management systems, it is a crucial necessity to have the exact commitment of top management, and also all levels and functions of the organization. If only an organization has this exact commitment of its top management, then it has the chance of developing successfully an OH&S policy, objectives, implementation and finally improvement of the performance in its OH&S management system (OHSAS 18002:2008).

On the other hand, the effectiveness of any management systems is very nearly dependent on the human factors including the culture, attitudes and beliefs within organizations. Those human factors either make any management system successful or break its success. So they should be valued very carefully as implementing the requirements recommended by guides to an organization (BS 8800:2004).

Figure 3.2 shows the importance of organization and interrelation between organizational job and personnel factors in health and safety.

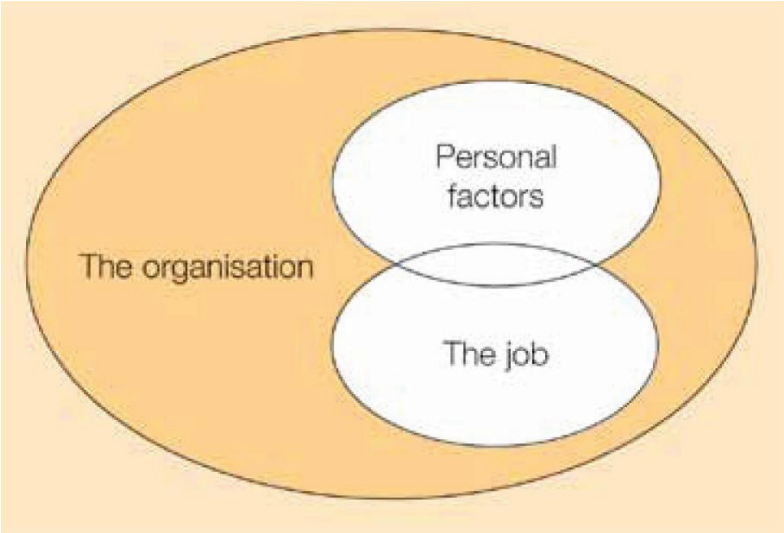


Figure 3.2 Human factors in industrial health and safety (HSE's booklet HSG 65: 1997, pg.15)

3.2 OH&S management systems methodology and model

OH&S management systems are based on the methodology which is applicable to all processes and named as Plan-Do-Check-Act (PDCA). Since PDCA can be applied to all processes, it is compatible with the methodology of "process approach" which ISO 9001 promotes to be used. So OH&S management systems have the capability of being integrated to the others, such as quality and environmental management systems in the same organization. Each step of the PDCA methodology where it is applied to an OH&S management system can be outlined as below:

Plan (P): Regarding the organization's OH&S policy, legal and other requirements; establish OH&S management system comprised of the objectives and necessary processes.

Do (D) : Implement plans to achieve objectives and standards.

Check(C): Monitor and measure progress and document the results against organization's OH&S policy and objectives together with legal and other requirements.

Act (A): Review against objectives and requirements and take appropriate actions for continual improvement of OH&S performance.

Figure 3.3 shows Plan-Do-Check-Act methodology application for OH&S.

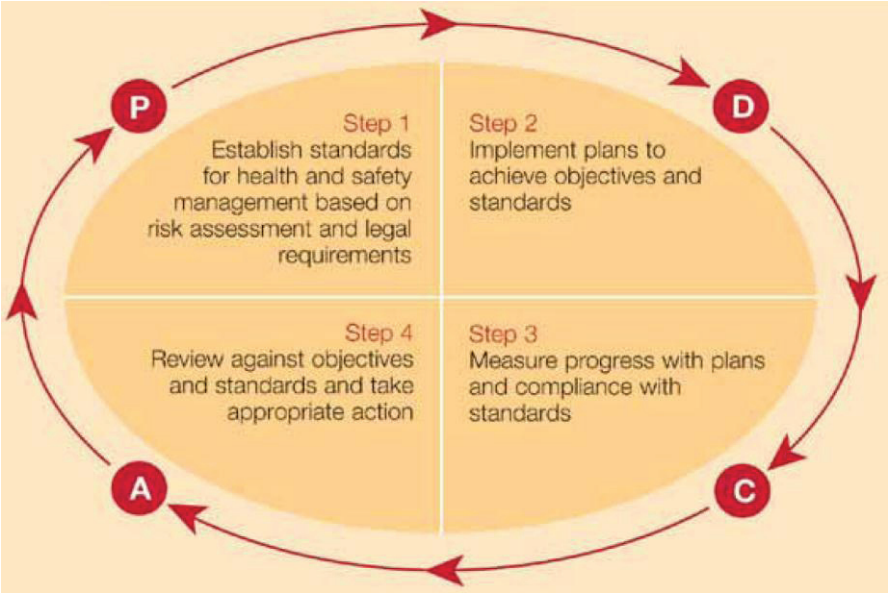


Figure 3.3 Plan-Do-Check-Act for health and safety (HSE's booklet HSG65:1997, pg.19)

An OH&S management system model should be shaped up together with the application of PDCA methodology to an organization's management system. Figure 3.4 shows such a model for OH&S management system.

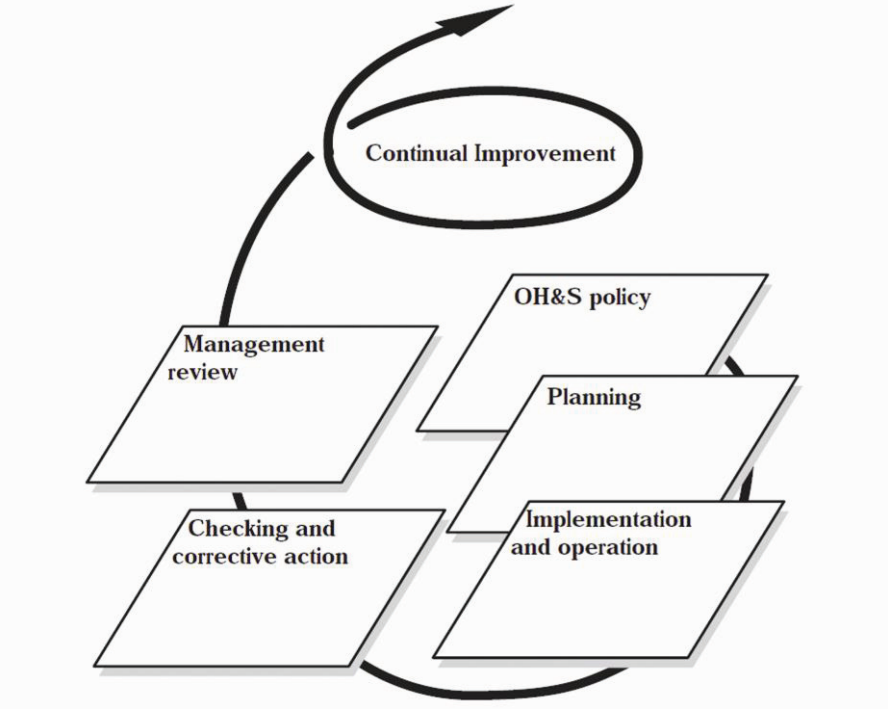


Figure 3.4 OH&S management system model for OHSAS Standard (OHSAS 18002:2008, pg.2)

3.3 OH&S management system elements (requirements)

3.3.1 General

Figure 3.4 also determines the elements (or requirements) of an OH&S management system recommended by OHSAS standard and guide.

In reality, there are not principal differences but some minor ones between the basic standards and guides which involve OHSAS18001:2007, OHSAS18001:2007, BS8800:2004, ILO-OHS: 2001, HSG 65:1997 regarding the elements of an OH&S management system. The elements of a successful OH&S management system proposed by BS 8800:2004 in the approach of HSG65 is given in Figure 3.5 for comparison by others.

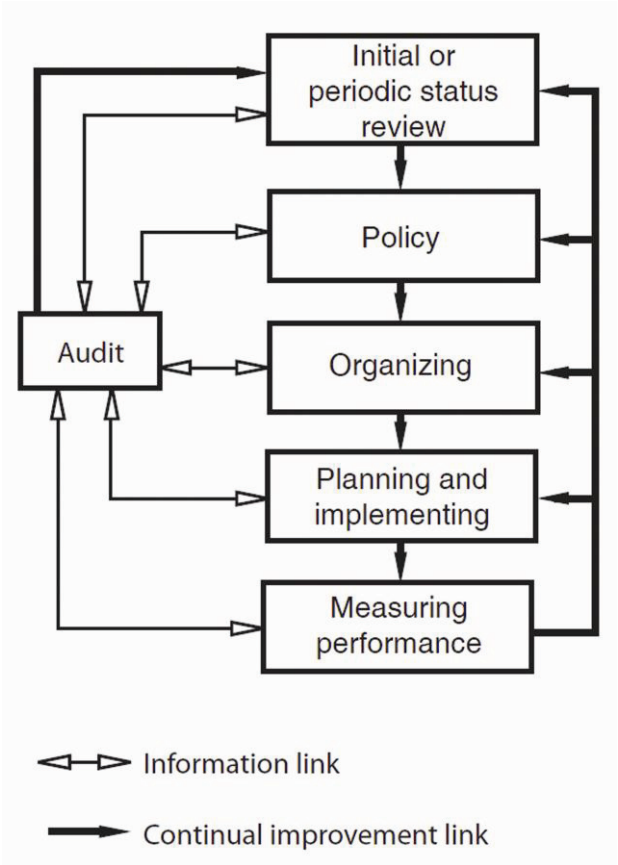


Figure 3.5 Elements of successful health and safety management based on the approach in HSG 65 (BS 8800:2004, pg.2)

The elements of an OH&S management figured out by ILO-OHS: 2001 and HSE's booklet HSG65:1997 are also shown in Figure 3.6 and in Figure 3.7 respectively for comparison purpose and seeing closeness to each other.

Figure 3.6 Main elements of the OH&S system (ILO-OHS: 2001, pg.5)

By the way, the main difference in the elements of the OH&S management system between standards and guides seems to be at "initial or periodic status review" topic. In some guides, this process is not noted as a separate element of the OH&S management system, but it is mentioned as a usual practice under whole process of establishment or it is worked under another element of OH&S management system. The same argument can be discussed for the element of "organizing" which is taken into account as a separate element in some guides, but it is covered in "planning" and "implementation" processes in the others.

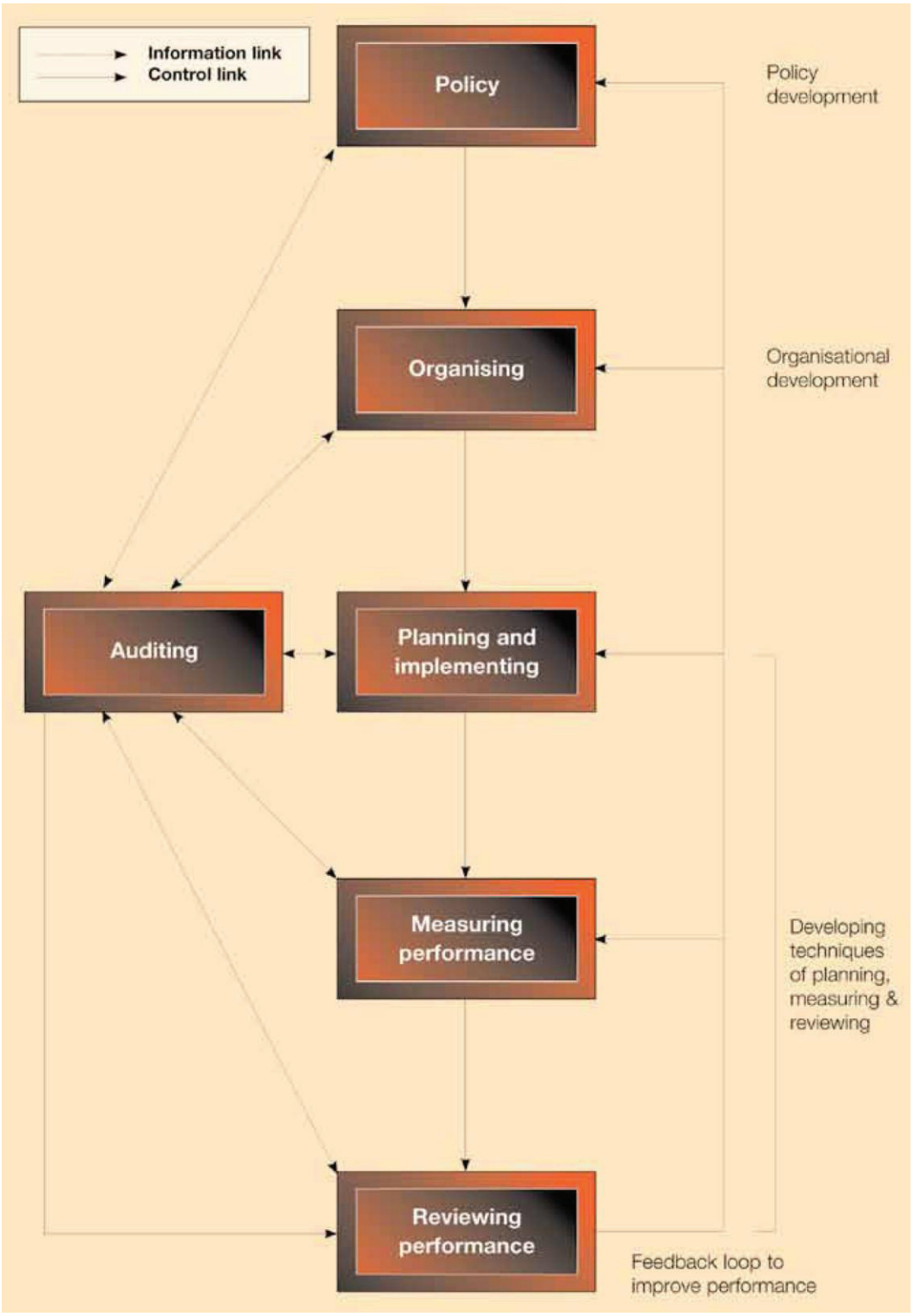


Figure 3.7 Key elements of successful health and safety management (HSE's booklet HSG 65:1997, pg.9)

As the result of discussion, it seems to be best to determine the elements of OH&S management system as:

1) Initial (status) review
2) OH&S policy
3) Planning
4) Implementation and operation
5) Checking and corrective action
6) Management review

The scope of this study covers the hazard identification, risk assessment and determining controls processes. OHSAS 18001:2007 and most of all other codes of practice and guidelines carry out this overall process under “planning” requirements of the OH&S management system. In order to show this situation, three main items composing “planning” requirements according to OHSAS 18001:2007 are listed below:

1) Hazard Identification, risk assessment and determining controls
2) Legal and other requirement,
3) Objectives and programme(s).

Hence it should be, now, possible to enable to see the whole picture of an OH&S management system and the position of the subject of the thesis in its entirety.

3.3.2 Summary of some elements (requirements) of OH&S management Systems related with the scope of the study

Since the scope of the study is limited with the overall process of hazard identification, risk assessment and determining controls, it is not needed to enter further explanation in the remaining part of the study for the other main elements (requirements) of OH&S management system which are “implementation and operation”, “checking and corrective action” and “management review”. However the items of “initial (status) review”, “OH&S policy” and the items of “legal and other requirements”, “objectives and programme(s)” in the scope of “planning” are tried to be summarized thinking that they are nearly related with the subject of the thesis.

By the way, the overall process of hazard identification, risk assessment and determining controls is presented comprehensively and separately in the subsequent chapter which is Chapter 4.

3.3.2.1 Initial (status) review

OHSAS 18001:2007 does not have initial (status) review topic as a requirement, but the guideline for it, OHSAS 18002:2008, does require an initial (status) review process in establishing OH&S management system. ILO-OHS: 2001 recommends initial (status) review as a part of planning and implementation processes. HSE's booklet HSG 65:1997 does not specify an initial (status) review process. BS 8800:2004 guides initial (status) review process as the first step of OH&S management system same as in OHSAS 18002:2008.

Initial review is carried out to provide necessary information about the current management system: its scope, adequacy and extent of implementation. It should be put into practice especially in all organizations that do not have an established and effective OH&S management system. If no OH&S system exists, or organization is newly established, then initial (status) review should serve as basis for OH&S management to be established.

An effective initial (status) review can use:

a) Direct inspection and measurements, interviews and checklist,
b) Previous management system audits or other reviews results,
c) Results obtained by consultations with workers, contractors or other necessary parties.

ILO-OHS: 2001 further recommends for an initial (status) review to analyze the data provided from the health surveillance of the workers together with the clarification of the following main items:

1) Current applicable national laws and regulations, national specifications and guidelines and other requirements to which the organization subscribes,
2) Hazards and risks to safety and health arising from the existing work environment and work organization,
3) Whether planned or existing controls are adequate to eliminate hazards or control risks.

The results of the initial (status) review should:

a) Be documented,

b) Be the basis for deciding about how OH&S management system to be establish and implemented,
c) Construct a baseline of measure from which continual improvement of OH&S management system can be confronted.

At the end of the initial (status) review process, OH&S management system is implemented to either the entire organization or to a subdivision; but in any case, the borders of workplace and the scope of the system should be made definite.

3.3.2.2 OH&S policy

OH&S policy is the commitment of top management of an organization, concisely

and clearly written, dated and signed by most senior manager, to establish an overall sense of direction of an organization's OH&S management system. In developing and implementing an OH&S policy, the uninterrupted and proactive involvement of top management is crucial.

The OH&S policy declared should be specific to the organization and appropriate to the size and nature of its activities and identified risks and it should be capable of guiding the setting of objectives.

An effective OH&S policy is required to include, as a minimum, the commitment of an organization about the items below:

1) Preventing injury and ill health,
2) Complying with applicable legal requirements (relevant OH&S national laws and regulations) and with the other requirements to which the organization subscribes,
3) Continually improving OH&S management and OH&S performance.

ILO-OHS: 2001 further recommend encouragement of the workers and their representatives to participate actively in all elements of OH&S management system for preventing diseases and incidents.

BS 8800:2004 recommends, for a good practice, a commitment in OH&S policy to a continual cost effective improvement in performance, by drawing the attention to the legal duty to reduce risk to acceptable level in accordance with as low as reasonably practicable (ALARP) principle.

3.3.2.3 Legal and other requirements (in the scope of “planning” requirements)

A procedure(s) is recommended for identifying and accessing the applicable legal requirements (laws, regulations etc.) and other requirements (such as contractual conditions, agreement with employees, non regulatory guidelines etc.), and all of those requirements should be considered in establishing, implementing and maintaining OH&S management system. The organization should keep the documentation up to date and should communicate the relevant legal and other requirements to persons in workplace and other related parties.

3.3.2.4 Objectives and programme(s) (in the scope of “planning” requirements)

The organization is recommended to establish, implement and maintain measurable

and applicable objectives which are consistent with OH&S policy. Some examples of types of objectives can be given as: objectives to increase or reduce numerical figures (e.g. to reduce the occurrence of an incident by 25%), objectives to increase controls or eliminate hazard, objectives to reduce workplace stress of workers and to increase awareness etc.

The organization is also recommended to establish a programme to achieve determined OH&S objectives and to review it regularly and improve it by adjusting or modifying where necessary. Resources such as financial and human resources or infrastructure should be determined, tasks to be performed should be examined, responsibility, authority and completion dates for each programmed task should assigned in the establishment of an effective programme.

CHAPTER 4

HAZARD IDENTIFICATION, RISK ASSESSMENT, DETERMINING CONTROLS

4.1 General

Hazard identification, risk assessment and determining controls constitute the foundation of a successful pro-active OH&S management system. In spite of that, it is very hard to mention from a consensus about terms and definitions for those main processes of OH&S management system. In other words, hazard identification, risk assessment and determining controls are the part of an OH&S management system, where there is the least consistency in terminology.

The terminology used at the topic of this chapter is the one used by OHSAS 18001:2007. Here, as it is understood; “hazard identification”, “risk assessment” and “determining controls” are each taken into account as interconnected but separate processes. On the other hand BS 8800:2004 does not discriminate those processes and combines all as an entire process under the term of “risk assessment”. In other words, where the “risk assessment” is depicted in BS 8800:2004, it encompasses the entire process of hazard identification, risk assessment and determining controls. ILO-OHS: 2001 uses the terminology of “hazard assessment”, “risk assessment” and “hazard preventions”. Although ILO-OHS: 2001 has a different terminology from both OHSAS 18001:2007 and BS8800:2004, it is seen that, in ILO-OHS:2001, the processes are preferred to be discriminated as in OHSAS 18001:2007. HSG 65:1997 regards the whole aspect as a process of controlling health and safety risks and achieves it in three steps as “hazard identification”, “risk assessment” and “risk control”, again, same as in OHSAS 18001:2007.

It should be noted that, in HSG 65:1997, hazard definition includes the potential to cause damage to property, plant, products or the environment. However BS8800:2004, ILO-OHS:2001 and OHSAS 18001:2007 do not refers to damage to property or workplace environment but only to harm human in terms of injury or ill health or combination of those.

The definitions of “accident” and “incident” also show variation in those standards and guides. OHSAS 18001:2007 defines “incident” as a generic concept or generic

term involving all work related events, in this respect, “accident” is in ”incident” but the one which causes to injury, ill health or fatality. On the other hand, “incident” by which no injury, ill health or fatality occurred is referred as a “near- miss”, “near- hit”, “close call” or “dangerous occurrence”. “Emergency situation” is, again, a particular type of “incident”.

On the contrary of OHSAS 18001:2007; in BS 8800:2004, ILO-OHS: 2001 and HSG 65:1997 “accident” and “incident” are defined discriminately as events, which causes injury, ill health or fatality and causes no harm respectively.

Another note is that OHSAS 18001:2007 does not use the term of “tolerable risk” any more, instead of that, “acceptable risk” is replaced by “tolerable risk”.

When come to tunnel construction, the terminology used in BS 6164:2004 “Codes of practice for safety in tunneling in the construction industry” mostly conforms with OHSAS 18001:2007 in the definition of risk assessment, while ABI (The Association of British Insurers) and BTS (The British Tunneling Society) : 2003 The joint code of practice for risk management of tunnel works in the UK coincides with BS 8800:2004 completely in the definition of risk assessment, and accordingly gather hazard identification, risk assessment and determining controls processes under an unique term of risk assessment. On the other hand Eskesen, S.D., Tengborg, P., Kampmann,J., Veicherts T.H.:2004 Guidelines for tunneling risk management : International Tunneling Association (ITA), Working Group No.2 follows a third way in between OHSAS 18001:2007 and BS 8800:2004, so that it combines hazard identification and risk assessment processes under the term of risk assessment and still holds risk mitigation as separate.

In general, terms and definitions used in this study are in compliance with OHSAS 18001:2007, but where it is seen useful in explanation, terms and definitions brought forward by other guides or codes are also registered.

“Hazard identification”, “risk assessment” and “determining controls” are required to be established, implemented and maintained by the organizations for;

- an overall purpose of understanding the hazards caused by activities in workplace,
- and being sure that any risks to persons arising from the hazards are at, or reduced to, acceptable level.

In many countries, it is legal requirement for employers to carry out systematic and documented hazard identification, risks assessment and determining controls processes for organization's risk control.

The items of the establishing, implementing and maintaining of an effective overall process of hazard identification, risk assessment and determining controls are shown in Figure 4.1

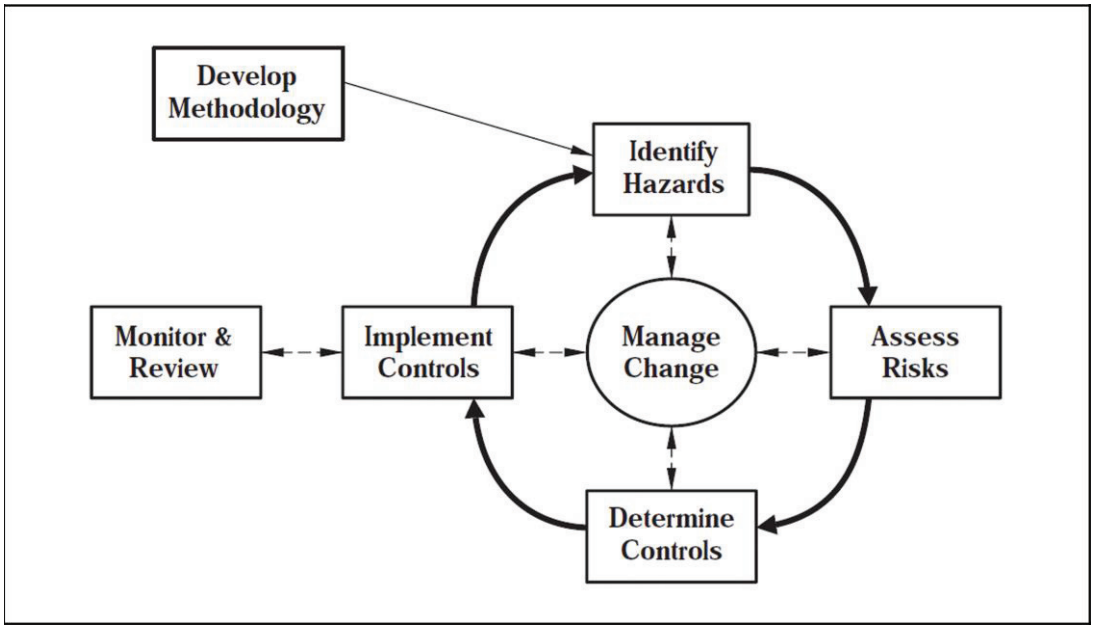


Figure 4.1 Overview of the hazard identification and risk assessment process (OHSAS 18002:2008, pg.15)

As it is seen in Figure 4.1, in an organization's OH&S management system, the overall process is achieved mainly by;

1) Developing methodology and procedures for hazard identification and risk assessment,
2) Identifying hazards,
3) Assess the risks related with identified hazards by estimating risk and determining the risk levels regarding whether they are acceptable,
4) Determining the adequate risk controls which are necessary and complying legal and other requirements and requirements which are subscribed by organization's OH&S policy and objectives.

Management of change is a central aspect affecting, and being affected by, all items in the overall process.

When identifying hazards, assessing risk and determining controls processes are finalized; the questions of how controls to be implemented and to be monitored and reviewed, will find their responses in implementation, checking and management review main processes of the OH&S management system. So, the processes of "implementing controls" and "monitoring and review" shown in Figure 4.1 are, in fact, the subjects of those main processes of the organization's OH&S management system and are accordingly performed in their scope.

BS 8800:2004 also gives a frame for the processes of risk assessment and control. It is shown in Figure 4.2 for comparison by OHSAS 18002:2008.

The overall process recommended by BS 8800:2004 for hazard identification, risk assessment and determining controls seems not to be different in general, but is more discriminated regarding the process items, compared by OHSAS 18002:2008. In this respect; the actions of "Classify Work Activities", "Identify Risk Control" (means existing risk control) and "Determine the Tolerability of the Risks" which are recommended to be carried out by BS 8800, are, in fact, parts in "identifying hazards" and "risk assessment" main processes comparing with OHSAS 18002:2008.

4.2 Developing a methodology and procedures for hazard identification and risk assessment

The methodologies used for hazard identification and risk assessment vary greatly thorough industries, from qualitative analysis to very complex quantitative analysis. Every organization should choose appropriate method or combination of methods regarding its scope nature and size. The detail, complexity, time, cost and availability of reliable input of a methodology are also taken into account by the organization as deciding the adequate method meeting its needs.

The qualitative methodology of risk evaluation is performed broadly by hazard identification, system analysis and consequence analysis; whereas the quantitative evaluation of risks which is necessary for an effective risk management is achieved by event frequency and probability analysis and consequence assessment. The qualitative methodologies are concerned with adequate identification of hazards in terms of causation and consequence.

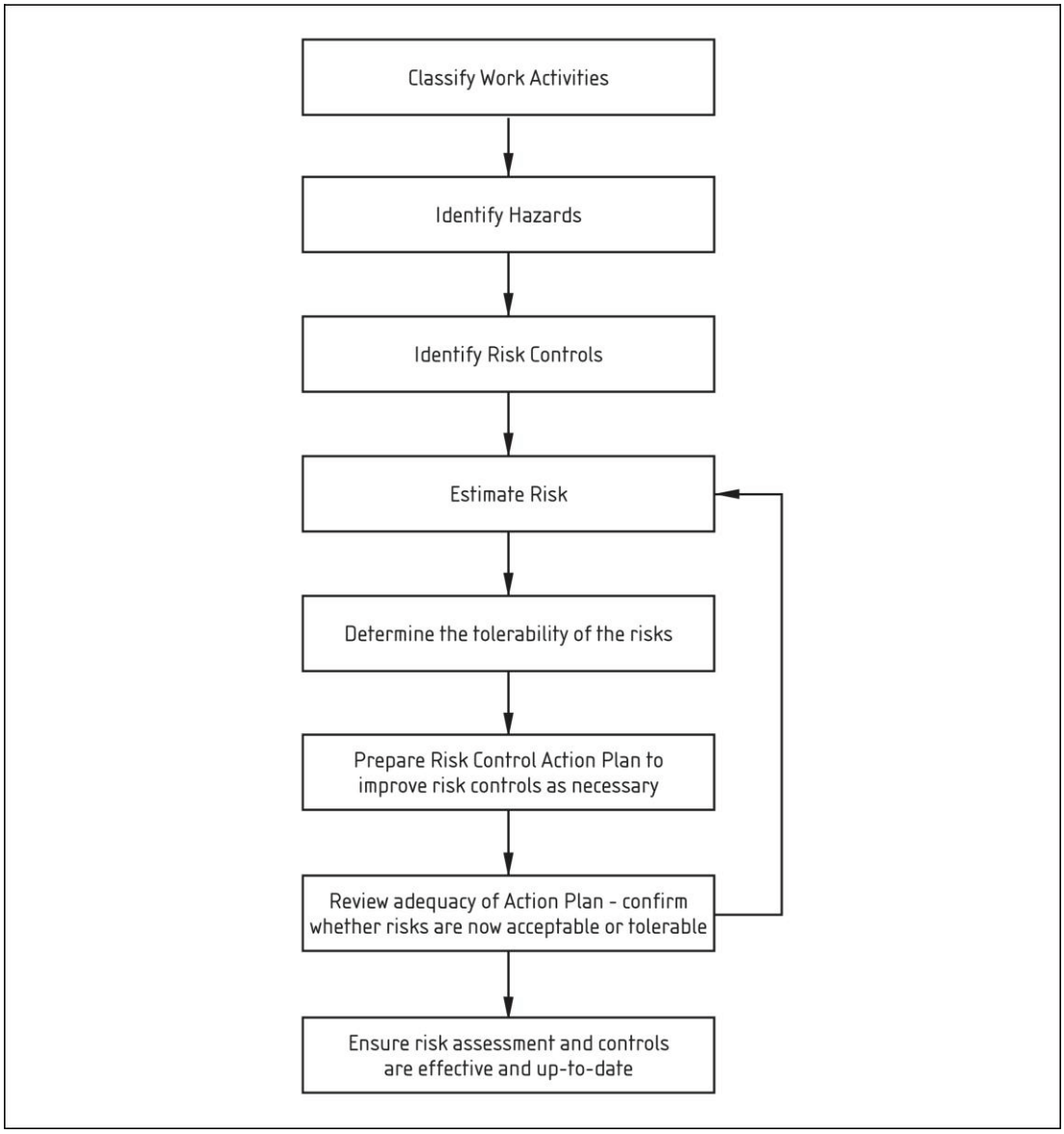


Figure 4.2 The processes of risk assessment and control (BS 8800:2004, pg.41)

The completeness, consistency and correctness are the key issues for qualitative methodologies. On the other hand the quantitative aspects of risk evaluation are concerned with the numerical estimation of the frequency and the consequences of hazardous events. Key issues for these aspects are reliability of the frequency and probability data and confidence in the mathematical model used in the methodology (Kirchsteiger, C.: 1998, pg.130).

Qualitative hazard identification techniques which are commonly used can be listed as below (Kirchsteiger, C.: 1998, pg.149-150):

- Obvious
- Previous occurrence or " near miss"

- Check list
- Indices
- Preliminary hazard analysis (PHA)
- " What if" analysis
- Hazard and operability study (HAZOP)
- Failure modes, effects and criticality analysis (FMECA)

The qualitative techniques can be used for risk assessment process where the needs of organization conform with, but mainly, it is obliged that the more complex quantitative methodologies are carried out for the reliable and effective risk assessment processes of bigger sized organizations having more complex activities.

The most commonly used quantitative risk analysis (assessment) techniques are listed below (Kirchsteiger, C.: 1998, pg.150):

- Block diagram (system analysis)
- Fault tree analysis (FTA) (system analysis)
- Event tree analysis (ETA)
- Cause-consequence diagram
- Human error analysis

To those quantitative risk analysis techniques, some others can be added which are: (Eskesen, S.D., Tengborg, P., Kampmann,J., Veicherts T.H:2004, ITA, pg.228-230)

- Decision tree analysis
- Multirisk
- Monte Carlo simulation

Since the thesis studied is mainly based on a case study, here, it is not entered to comprehensive explanations of those risks assessment techniques, but the risk assessment methodology followed particularly in the case study is described exhaustively in the related sections together with the methods used in hazard identification and determining controls processes.

However, for a general information, some common used samples of qualitative and quantitative methodologies for hazard identification and risk assessment are compared regarding their advantages and disadvantages of use in Table 4.1.

Table 4.1 The risk assessment methodologies comparison table (Özkılıç, Ö. : 2005, Section 4, Table 5a and 5b)

Criterias	What if...?	PHA	JSA	Check List	HAZOP	FMEA/ FMECA
Need for necessary document	Very little	Medium	Very much	Medium	Very much	Very much
Team work	With an analyst	With an analyst	Team work	Team work	Team work	Team work
Experience of team leader	Medium	Medium	Very much	Medium	Very much	Very much
Qualitative/ Quantitative	Qualitative	Qualitative	Qualitative	Qualitative	Qualitative	Qualitative
Aimed at a special branch	Basic procedure work	Applicable to all sectors	Applicable to all sectors	Applicable to all sectors	Chemical Industry	Electrical Machinical works
Application success rate	It is not singly enough to define risks Success depends on experience of team leader	It is primary risk assessment method; It is not singly enough to define risks; Success depends on experience of team leader	If job definition of people is defined well; it will be successful	Success rate depends on checklists when prepared to specialists	It is rather a difficult method; It requires high experience and high performance of team members	Success rate increases when FTA is done before analysis

Criterias	Safety Audit	FTA	ETA	L Type Matrix	X Type Matrix	Reason-result analysis
Need for necessary document	Very little	Very much	Very much	Very little	Very much	Very much
Team work	With an analyst	Team work	Team work	With an analyst	Team work	Team work
Experience of team leader	Medium	Very much	Very much	Medium	Very much	Very much
Qualitative/ Quantitative	Qualitative	Qualitative / Quantitative	Qualitative / Quantitative	Qualitative	Qualitative	Qualitative / Quantitative
Aimed at a special branch	Applicable to all sectors	Applicable to all sectors	Applicable to all sectors	Basic procedure work	Applicable to all sectors	Applicable to all sectors; but especially chemical industry
Application success rate	It is not singly enough to define risks Applicable to all sectors; Success depends on experience of team leader	It requires high experience and high performance of team members It is rather an effective method to define risks	It requires high experience and high performance of team members It is rather an effective method to define risks	It is applicable to basic procedure works; Success rate depends on experience of team leader	It is applicable to all sectors; Success rate depends on experience of team leader	It requires high experience and high performance of team members It is rather an effective method to define risks

OHSAS 18002:2008 gives also some examples of risk assessment tools and methodologies by showing their strengths and weaknesses in use. Table 4.2 shows the details of this comparison.

Table 4.2 Comparison of some examples of risk assessment and methodologies (OHSAS 18002:2008, Annex D)

Tool	Strengths	Weaknesses
Checklists/ Questionnaires	• Easy to use • Use can prevent "missing something" in initial evaluations	• Often limited to yes/no answers • Only as good as the checklist used - it might not take into account unique situations
Risk matrices	• Relatively easy to use • Provides visual representation • Does not require use of numbers	• Only 2-dimensional - cannot take into account multiple factors impacting risk • Predetermined answer might not be appropriate to the situation
Ranking/Voting tables	• Relatively easy to use • Good for capturing expert opinion • Allows for consideration of multiple risk factors (e.g. severity, probability, detectability, data uncertainty)	• Requires use of numbers • If the quality of the data is not good, the results will be poor • Can result in comparison of incomparable risks
Failure modes and effects analysis (FMEA); Hazard and operability studies (HAZOP)	• Good for detailed analysis of processes • Allows input of technical data	• Needs expertise to use • Needs numerical data to input into analysis • Takes resources (time and money) • Better for risks associated with equipment than those associated with human factors
Exposure assessment strategy	• Good for analysis of data associated with hazardous materials and environments	• Needs expertise to use • Needs numerical data to input
Computer modeling	• If relevant and sufficient data are available, computer modeling can give good answers • Generally uses numerical inputs and is less subjective	• Significant time and money needed to develop and validate • Potential for over-reliance on the results, without questioning their validity
Pareto analysis	• A simple technique that can assist in determining the most important changes to make.	• Only useful for comparing similar items, i.e. is unidimensional

Whatever methodology is used by the organization, a participative approach to hazard identification, risk assessment and determining controls processes, gives the chance of a common agreement between the work force, safety representatives and management of OH&S about the judgment that the organization's OH&S procedures:

- covers necessary and workable aspects,
- are based on shared perceptions of hazards and risks of all sides and persons in organization's OH&S management,
- are believed that they will succeed in preventing harm (BS8800:2008).

As an organization is carrying out the hazard identification, risk assessment and determining controls processes to constitute its OH&S management system, it should not forget that a participative approach considering all sides and persons of OH&S will contribute to the promotion of the positive safety culture in workplace which is a crucial aspect for a successful and effective OH&S management system.

4.3 Hazard Identification

4.3.1 General

Hazard is source, situation or act, or a combination of those with a potential for harm in the way of human injury or ill health. So hazard identification is the determination proactively of all those sources, situations or acts or their combinations arising from activities of an organization in its workplace. For example; moving machinery is a source, working at height is a situation and manual lifting is an act which may be identified as hazard. Hazards can be physical, chemical, biological or psychological and they should all be considered in process of hazard identification.

A hazard identification process team has three main questions to enable to identify hazards (BS 8800:2004):

- Is there a source of harm arising from inside the workplace or originating from the outside?
- Which persons or groups of persons could be harmed?
- How could harm come into existence?

Hazard identification should cover all persons who access to the workplace (e.g. employees, customers, service contractors, visitors etc.), because the actions of all those parties (e.g. activities of employees, use of the products of customers or

services supplied contractors, behavior or degree of familiarity of visitors with the workplace) have the same importance in arising hazard and risk at the workplace.

The activities at the work place are not all routine ones but also there are non-routine activities such as occasional ones or emergencies. A hazard identification process does not skip any kind of activity and is applied to both routine and non-routine activities and situations in the workplace. For instance, the activities such as equipment cleaning or non-scheduled maintenance, plant or equipment start-up or shut-down, extreme weather conditions, utility disruptions, visits to workplace, temporary arrangements should be included in hazard identification process as the non-routine activities.

BS 8800:2004 gives the possible ways of classifying work activities as below (they can be separate or in combination) :

- Stages in the production process,
- Planned and reactive work,
- Defined tasks,
- Tasks carried out by subcontractors,
- Organization's premises
- Activities related with equipments: installation, normal operation, maintenance and repair, disposal,
- Start-up and shut-down activities for plants and equipments,
- Activities of plant on the workplace provided and maintained by other contractors (subcontractors)

Hazards to be identified for an organization's workplace should not be considered as sources, situations or activities existing only inside the workplace. The foreseeable hazards which originate outside the workplace but can have an impact within the workplace should also be addressed in the process of hazard identification. An any case, organizations are obliged to consider hazards arising from beyond the boundary of the workplace if there is particularly a legal duty of taking action about.

For an effective hazard identification process, the following sources of information should be considered:

- Legal requirements prescribe how hazards should be identified,

- Other requirements described by standards, guidelines, codes of practice related with hazard identification,
- Requirements subscribed additionally by organization for hazard identification specific to its workplace in its OH&S policy,
- Information on the facilities, processes and activities of the organization, including :
    - Site plan, workplace design, traffic plans,
    - Process flowcharts and operational manuals,
    - Equipment specifications,
    - Product specification,
    - Inventories of hazardous materials
- Records of incidents,
- Monitoring documents,
- Audits, reviews and assessments previously reported,
- Results of activities in workplace for process review and improvement,
- Employees and other related parties' participation,
- Input from employees and other interested parties,
- For the similar organizations;
    - Identified typical hazards,
    - Reports of incidents that occurred,
    - Documents on the best practice,
- Information from other management systems such as quality or environment management.

Persons' capabilities, behavior and limitations which constitute the human factors are very important aspect in evaluating hazards in the workplace. For instance ease of use, potential of operational errors, operator and user fatigue or stress are direct source of hazards related with human factors and they should be considered substantially in hazard identification process. If it is summarized, the organization's hazard identification should involve the following and their interactions:

- The nature of work such as workplace layout, work load, work properties, information about operators etc.,
- Conditions of the environment such as heat, noise, lighting, air quality etc.,

- Human habits, attitude, temperament etc.,
- Psychological capabilities cognition, attention or physical variation of people.

4.3.2 Methodology and procedures for hazard identification

Hazard identification is the most critical step in the entire risk evaluation of an organization's OH&S. Because if it is not complete, consistent and correct, then it is impossible to recover in further steps, and everything is constituted on a false structure (Kirchsteiger, C.: 1998, pg.142).

So it has a crucial importance for the organization to establish specific hazard identification tools and techniques that are adequate to the nature, size and scope of its OH&S management system and to ensure, at the end of the process, the completeness, consistency and correctness of hazards identified.

On the other hand, the persons conducting hazard identification process should have appropriate knowledge about the work activities which is carried out in workplace. Besides that they should be competent people and have advance experience in the hazard identification methodologies. Those are inevitable organizational needs to establish complete, consistent and correct hazard identification and to have an effective OH&S management system.

For a successful hazard identification, the organization should have such an understanding that information used in hazard identification process to be collected from a variety of sources including especially from the people who have high experience and knowledge of tasks, activities, processes and systems in its workplace. Some of those useful sources can be listed as below:

- Workflow and process analysis, their potential to create unsafe conditions,
- Incidents reviews and subsequent analysis,
- Safety tours and inspections,
- Investigation of the causes behind the unsafe behavior by making observations of behavior and work practices,
- Interviews and surveys, participation of people,
- Monitoring and assessment of hazardous chemical and physical agents exposure,
- Benchmarking.

Checklist can be used in hazard identification. They should be taken as a tool of the initial hazard identifications just to see what types of potential hazards to be considered. But it should not be conferred over reliance to the use of checklist and tried to have specific checklists for work area, process, plant and equipment.

In Table 4.3, a prompt list for physical, chemical and biological hazards and to what incident they lead is listed down.

Table 4.3 A prompt list for hazards and their consequences (BS8800:2004, pg.45)

a) Physical hazards:
— slippery or uneven ground leading to slips/falls on a level;
— work at heights, leading to falls (linked to factors such as the distance of the fall);
— falls from height of objects such as tools or materials, leading to impacts on passers by;
— inadequate space to work, such as low headroom, leading to head impacts;
— poor ergonomics (e.g. bad posture or repetitive work), leading to acute or chronic health effects;
— manual lifting/handling of materials, etc., with the potential for back, hand and foot injuries (linked to factors such as the characteristics of the load);
— trappings, entanglement, burns and other hazards arising from equipment;
— transport hazards, either on the road or on premises/sites, while travelling or as a pedestrian (linked to the speed and external features of vehicles and the road environment);
— fire and explosion (linked to the amount and nature of flammable material);
— harmful energy sources such as electricity, radiation, noise or vibration (linked to the amount of energy involved);
— stored energy, which can be released quickly and cause physical harm to the body (linked to the amount of energy);
— frequently repeated tasks, which can lead to upper limb disorders (linked to the duration of the tasks);
— unsuitable thermal environment, which can lead to hypothermia or heat stress;
— violence to staff, leading to physical harm (linked to the nature of the perpetrators);
— ionising radiation (from x- or gamma-ray machines or radioactive substances);
— non-ionising (e.g. light, magnetic, radio-waves).

b) Chemical hazards:
— substances hazardous to health or safety due to inhalation (such as carbon monoxide (CO) the hazard would be linked to the amount of CO);
— contact with, or being absorbed through, the body [such as acids the hazard would be linked to the strength and amount of the acid];
— ingestion (i.e. entering the body via the mouth), such as lead paint;
— stored materials that degrade over time (such as oxidizers);
— lack of oxygen.

Table 4.3 A prompt list for hazards and their consequences-Continued

c) Biological hazards: — biological agents, such as bacteria or viruses that might be: i) inhaled; ii) transmitted via contact with bodily fluids (including needle-stick injuries). The hazard would be linked to the nature of the pathogen; iii) ingested (e.g. via contaminated food products).
d) Psychological hazards: — excessive workload, lack of communication or control, workplace physical environment, leading to stress (linked to the magnitude and duration of stressors); — physical violence, bullying or intimidation within the workplace, leading to stress; — involvement in a major incident, leading to post traumatic stress. The hazard would depend on the nature of the incident.

In any case, relevant checklists prepared are helpful and applicable, more often, those general checklists are expanded to a specific list of hazards for a particular section of industry (Kirchsteiger, C.: 1998, pg.133).

In Table 4.4, Table 4.5, Table 4.6 and Table 4.7, for construction industry, potential construction hazards, the construction equipments, tools and materials are shown respectively.

Table 4.4 Potential construction hazards (Reese, Charles D., Eidson, James V., 2006, pg.18)

• premature explosions • rollover • electrocution • mounting and dismounting heavy equipment • noise • dust • whole body vibration • exhaust emissions and carbon monoxide • whipping air hoses and other hazards of compressed air equipment • cave-in • burns • working on areas without guards	• hand/arm vibration • moving of heavy equipment • concrete handling • working with sharp objects • using hand and power tools • wet/slippery surfaces • mists • ladder and scaffolds • fumes • vapors • radiation • gases • lifting and carrying heavy materials • working off precarious surfaces

Table 4.5 Construction equipment (Reese, Charles D., Eidson, James V., 2006, pg.18)

- Scrapers
- Graders
- Bulldozers
- End-loaders
- Drills
- Cranes
- Trucks
- Ditch Witches
- Derricks
- Backhoes
- Forklifts
- Helicopters
- Pumps
- Generators
- Ventilation fans
- Ladders
- Scaffolds
- Tampers
- Jackhammers
- Chain saws

Table 4.6 Construction tools (Reese, Charles D., Eidson, James V., 2006, pg.18)

- Radial saws
- Table saws
- Drills
- Chippers
- Grinders
- Powder-actuated guns
- Lathes
- Planners
- Riveters
- Sanders
- Hammers
- Crowbars
- Chisels
- Screwdrivers
- Axes
- Shovels
- Tin snips
- Pliers
- Knives
- Knee kickers
- Staplers

Table 4.7 Construction materials (Reese, Charles D., Eidson, James V.: 2006, pg.18)

- All wood products
- Steel beams
- Stone products
- Bricks
- Concrete blocks
- Tiles
- Electrical wire
- Nails
- Bolts and nuts
- Rebar
- Sheetrock
- Sheet metal
- Insulation
- Soils
- Pipes
- Fiberglass
- Paneling
- Glass
- Fixtures
- Concrete
- Chemicals
- Compressed gases

For tunneling works, related with OH&S, principal occupational health hazards and possible symptoms and/or consequences are listed in Table 4.8 in the reference of BS 6164:2001.

Table 4.8 Principal occupational health hazards (BS 6164:2001, pg.8-9)

Hazard	Occurrence	Possible symptoms and/or consequences	Text reference
A. Physical			
1. Noise	-Prolonged exposure to high noise levels. -Pneumatic tools such as clay spades or rock drills. -Machinery.	Long-term irreversible hearing loss.	4.4.2, 4.4.3, 4.4.4, 19.1, 19.2
2. Manual handling (lifting, carrying, pushing/pulling)	Hand excavation techniques. Erection of lining by hand. Use of heavy, awkward, slippery, sharp tools.	Pain including low back pain and restricted body movements that can lead to permanent disability. Prolapsed disc. Muscle/tendon damage.	4.4.3, 8.3, clause 21
	-Repetitive, frequent or prolonged operations requiring force, gripping, squeezing of hands, rotation of wrists. -Awkward posture.	Work-related upper limb disorders. Pain, numbness and restricted body movement which can lead to permanent disability.	4.4.3, 19.3
3. Vibration	Prolonged exposure to high vibration hand-held tools. Concrete/rock breakers. Clay spades. Percussive drills.	-Hand arm vibration syndrome. Tingling or pins and needles in the fingers, and numbness. Whiteness at the fingertips when exposed to the cold. -Finger paleness followed by a rapid red hand flush, plus finger throbbing. More frequent attacks causing hand pain and reduced dexterity. -Eventually blue-black appearance of the fingers.	4.4.3, 4.4.4, 19.3
4. Heat	-Hand excavation in conditions of high temperatures, high humidity, or low rate of air movement. -Exacerbated by working in compressed air.	Heat stress and strain. Exhaustion. Increased heart rate and body temperature and sweating and salt imbalance. Fainting.	4.4.5, note to clause 11, 15.3, 15.6
5. Hyperbaric atmosphere	Work in compressed air.	Decompression illness. Signs and symptoms can include: *Acute:* Limb joint pains, skin rashes, itching, mottling, numbness, tingling, weakness, paralysis, visual disturbance, unconsciousness, convulsions. *Chronic:* Bone necrosis.	clause 11

Table 4.8 Principal occupational health hazards- Continued

B. Chemical			
1. Cementitious materials, additives, epoxy resins	Prolonged direct skin contamination of hands, forearms, legs from concreting, grouting, slurries, rock bolting. Application of sprayed concrete.	Redness, itching, scaling, blistering, cracking and bleeding of exposed skin causing irritant or allergic dermatitis.	4.4.5, 7.13.2, 7.16, Table 4, 8.3.5
2. Respirable crystalline silica	Machine cutting of rock. Application of sprayed concrete, drilling, breaking, crushing, conveying, cutting, loading of rock.	Increasing breathlessness, heart failure, acute silicosis, accelerated silicosis, lung fibrosis.	4.4.2, 4.4.3, 4.4.4, clause 16
3. Other respirable dusts	Machine cutting of rock. Application of sprayed concrete, drilling and blasting.	Irritation of respiratory tract. Accumulation of dust in the lungs.	7.8, clause 16
4. Solvents	Skin contact, contamination of tunnel atmosphere. Contaminated land.	Principally skin irritation including dermatitis. Nausea and giddiness.	4.4.3, 15.4.3.11
5.Hydrocarbons	Particulates from diesel engine exhaust emissions.	Irritation of eyes and respiratory tract. Might be a link with cancer (cause unclear).	15.4.3, 24.4.1
C. Biological			
Contaminated water or soil	Infection through poor hygiene practices, skin cuts and abrasions or rubbing eyes when working in contaminated land or water sewage.	Weil's Disease (Leptospirosis) — a bacterial infection carried in contaminated water and soil. Early symptoms include sudden high temperature, loss of kidney function, influenza-like illness, joint and muscle pains. Conjunctivitis and jaundice can occur.	4.4.3, 4.4.5, clause 26

Improvement of soil conditions is most common technical operation faced frequently in tunnel construction. The materials used for this purpose are mostly hazardous materials for ill health of workforce. In Table 4.9 those commonly used soil conditioning materials are listed with their typical use and hazards caused by them.

Table 4.9 Soil conditioners (BS 6164:2001, pg.33)

Material	Principal components	Typical use	Hazard
Bentonite	Sodium, Potassium, Calcium montmorillonite	As a slurry in slurry shields and to modify the soil in EPB machines; as a ground support and lubricating medium round jacked pipes and in TBMs.	Respirable dust in dry state. Slippery when wet. Skin irritant.
Polymers	*Artificial:* — polyacrylamides — polyacrylates — carboxymethyl cellulose	Additives to bentonite to modify viscosity. Lubricant.	Generally considered to be non-toxic, but refer to safety data sheets for specific hazards and relevant control measures. Slippery when wet.
	Natural: — starch — guar		
Foams and foaming agents	*Synthetic foams containing:* — synthetic detergents — glycol ether foam booster — fluorocarbon	For modifying soils to improve handling characteristics.	Toxic, irritant. See safety data sheet for hazards and control measures.
	Protein foams containing: — protein foaming agent — glycol based foam booster		
Other materials	Hexylene glycol	Solvent used with foam.	Toxic, irritant. See safety data sheet.
	Ethylene glycol ether	Solvent used with foam.	Toxic, irritant. See safety data sheet.
	Soda ash	Increase pH for use in acidic conditions.	See safety data sheet for specific hazards and control measures.
	Lime Cement	Possible modifier to improve characteristics at disposal state.	
	Lignosulfonates Complex phosphates	Dispersants, thinners in bentonite slurries.	

In tunneling works, the contaminants accumulated in the atmosphere of workplace are one of the important hazard sources causing explosion or fire besides their toxic effect with catastrophic consequences. So they should be taken into account carefully in hazard identification process. Most commonly encountered atmospheric contaminants in tunneling works and hazards arising from them, their limits and sources are listed in Table 4.10.

Table 4.10 Summary of most commonly encountered atmospheric contaminants (BS 6164:2001, pg.65)

Contaminant		Relative density	Hazard	O.E.S.[a]		Explosive limits		Principal sources
				Long-term limit[b]	Short-term limit[c]	Lower %	Upper %	
Carbon monoxide	CO	0.97	Toxic	30 ppm	200 ppm	12.5	74.2	Explosives, engines
Carbon dioxide	CO_2	1.53	Asphyxiant	5 000 ppm	15 000 ppm	N/A	N/A	Natural, engines, welding explosives
Nitrogen oxides	NO NO_2	1.04 2.62	Toxic Extremely toxic	25 ppm 3 ppm	35 ppm 5 ppm	— 	— 	Explosives, engines Welding
Methane	CH_4	0.55	Explosive and asphyxiant	—	—	4.4	14	Natural
Hydrogen sulfide	H_2S	1.19	Toxic and explosive	10 ppm	15 ppm	4.3	45.5	Natural
Sulfur dioxide	SO_2	2.26	Toxic	2 ppm	5 ppm	—	—	Natural
Propane Butane Acetylene		1.55 2.05 0.91	Explosive and asphyxiant	600 ppm	750 ppm	2.2 1.5 1.5	9.5 8.5 100	Leakages Leakages Leakages
Ammonia	NH_3	0.59	Toxic	25 ppm	35 ppm	15.0	28.0	Organic material
Volatile organic compounds	various	—	Toxic and explosive	—	—	approx. 1.0[d]	—	Contaminated land
Organic solvents	various	—	Toxic	—	—	—	—	Industrial discharge
Oxygen deficiency	O_2	1	Asphyxiant	—	<19 % O_2	—	—	Natural, induced
Oxygen enrichment		1	Increased fire risk	—	>23 % O_2	—	—	Stored oxygen in tunnel, airlocks

Table 4.10 Summary of most commonly encountered atmospheric contaminants- Continued

Petrol/diesel vapour	—	>2.0	Explosive	—	—	approx. 1.0	7.5	Spillage
Ozone	O_3	1.66	Toxic	—	—	—	—	Welding
Radon	Rn	—	Radioactive	N/A	N/A	—	—	Natural

a Occupational Exposure Standards (c Guidance Note EH 40 (23) for further information.

b 8h, time-weighted average

c 15 min.

d Dependent on constituents

N/A = Not Applicable

A further opportunity to improve checklist is to study of previous hazardous occurrences or near misses. In this respect, hazard identification will include a review of relevant incidents occurred in the past in the organization or in the other similar organizations (Kirchsteiger, C.: 1998, pg.142).

4.4 Risk assessment

4.4.1 General

Following a comprehensive identification of hazards in the workplace by considering all routine and non-routine activities, covering all persons accessing to workplace and including hazards originated outside of the workplace but having impact on persons in the workplace; subsequent stage is the assessment of risks corresponding to each hazards identified.

Risk is defined, as the combination of the likelihood of an occurrence of a hazardous event or exposure and its severity of injury or ill health that can be caused by. Accordingly, risk assessment is a process of evaluation of risks arising from hazard or hazards in the base of the adequacy of any existing controls initially determined during hazard identification stage. The results of risk assessment provide the data required for deciding whether the risk is acceptable or not which is needed in further step of determining necessary controls. In other words, risk assessment also covers deciding whether the risk is acceptable, and, hence, further control measures are required or not, on the base of the adequacy of any existing controls.

Risk assessment is the part of planning of an OH&S management system for which it should be spent enough time and be shown enough care because the results obtained will constitute the criteria for deciding whether additional controls, which are the final objective of a risk control management, are needed or not.

For a correct and useful risk assessment process, obtaining reliable, consistent and complete information and choosing a methodology as much adequate as it is; are very important matters. The inputs to the risk assessment process, without thinking they are limited to, include information about the following items (BS 8800:2004 and OHSAS 18002:2008):

- Location where the work is carried out,
- Tasks which are carried out, their duration and frequency,
- Who normally or occasionally carries out the tasks,
- Training level that personnel receive about the task,
- The human capabilities, behavior, competence and experience,
- Proximity of other personnel (e.g. contractors, public, cleaners, visitors) who might be affected by hazardous job,
- Proximity and scope for hazardous interaction between activities,
- Security arrangement in the workplace,
- Any existing written system of work, or any permit-to-work procedures prepared for hazardous tasks,
- Machinery and powered hand tools used in workplace,
- The instructions of manufacturers and suppliers for operation and maintenance of plants, equipments and facilities,
- Materials handled; their weight, surface character, size and shape,
- Distances and heights that materials have to be moved by hands,
- Availability and use of control such as ventilation, personnel protective equipment(PPE), guarding etc.,
- Abnormal conditions such as electricity and water supply interruptions, or other process failures,
- Environment conditions affecting the workplace,
- Failure of safety devices, plant and machinery components or their degradation due to exposure to process materials or elements,
- Reactive monitoring data related to incidents occurred with specific work activities,

- Findings of any existing risk assessment relating to hazardous work activity,
- Previous unsafe acts occurred by persons carrying out the activity or by other persons such as subcontractors, visitors etc.,
- Accessibility to, and adequacy or condition of, emergency equipment, emergency escape plans, emergency communication facilities, external emergency support,
- Health related data (e.g. toxicological or epidemiological data)
- Any legal or other requirements about how the risk assessment to be performed, what constitutes an acceptable risk, e.g. permissible exposure levels etc.,
- Reliability and accuracy of data to be used in the risk assessment process.

The clear description of scope of the risk assessment is an other important aspect in risk assessment process, for instance, the risk assessment related to a particular plant should clearly record that it is carried out for a normal operation and “cleaning and maintenance” activities are subjected to a separate risk assessment process or it involves both of it. So it is openly communicated among the team performing risk assessment that the correct scope and coverage is achieved at the end of the process.

4.4.2 Risk assessment methodologies and other considerations for risk assessment

As mentioned before, the existing control measures of the organization are also identified together with the identification of hazards. Risk assessment, which is mainly determination of likelihood of the harm and severity of the consequences of hazardous events, should consider these existing control measures as the base in seeking the likelihood of the harm. The extent of reliability of provided frequency data, as the factor affecting directly the result of the risk, should be taking into account in deciding the acceptability of the risk, so that the higher level of uncertainty in data means the greater need for caution. For increasing the completeness of risk assessment data, consultation with and appropriate participation by workforce and applicable regulatory guidance and other requirements specified by agencies publishing standards, guides, codes of practice, should be used as the valuable tools.

The organization has the chance of choosing one of the risk assessment methodologies in estimating its risks for overall the workplace, on the other hand, if it sees necessary, may vary the risk assessment method for a particular area of workplace or for specific works, but by keeping it as a part of the overall strategy. The key issues, here, are, the confidence in the mathematical model used or completeness, consistency or correctness of methodologies applied.

Complex mathematical calculations may be required in OH&S risk assessment for some big sized or complex process plants. In fact, in some countries, where this degree of complexity is required, it is specified by sector-specific legislation.

However, in many circumstances, if not necessary, simpler methodologies, even qualitative ones, are preferred to be carried out in performing risk assessment, instead of the complex quantitative ones which require more time, more cost, more competence and more number of appliers. Any how, it should not be forgotten that these simpler methods typically involve a greater degree of judgment, and need more experience in process and its activities, more consultations and more participations.

The organizations may take the advantage of risk assessments previously developed for typical activities in different workplaces of other organizations. Although this performance helps to increase the speed and efficiency of the risk assessment process, it should be used as a starting point for a more specific risk assessment and it should be adapted to be appropriate to the particular workplace.

Where descriptive categories are used in risk assessment methodology for assessing likelihood or severity, such as “likely”, ”unlikely” or “severe”, “considerable” respectively; a serious care should be shown for clear and concise definitions of those categories, so that interpretation of different individuals should be consistent.

Risk sensitive persons such as pregnant workers; vulnerable groups such as inexperienced employees; and susceptible individuals to particular tasks such as color-blinded individuals should substantially be taken into account in risk assessment process.

Another important aspect in risk assessment process related with OH&S is the way of approaching in deciding about specific hazards that could cause impaction on large numbers of persons. Any organization should determine how the risk

assessment method will consider the number of persons that might be impacted by a particular hazard, and in any case, it should give more careful considerations for hazards that could cause harm to large numbers of people, even if it has a low likelihood against such severe consequences.

If sampling approach is used for various situations or locations in risk assessment process in an organization, it should be ensured by organization that the application results sufficient and adequate samples to represent all situations or locations under consideration in the workplace.

4.5 Management of change

The management of change has a central position affecting and been affected by each stage of overall hazard identification, risk assessment and determining control processes from the beginning till the end of the project. Any changes that can impact OH&S hazards and risks should be managed and controlled by the organization. Changes include processes, activities, equipments, materials, organization's structure, personnel, management system etc. In the duration of initial planning stage, as the existing control measures in the organization are tried to be identified, changes in the items mentioned above are also noted down and considered in hazard identification, risk assessment and determining controls processes. Management of change process is initiated under the conditions below:

- The site organization's structure, the use of contractors, staffing etc. changed in considerable extent,
- The work procedures, work practices, designs, specifications or standards are renewed or revised,
- Technology including software, equipments, facilities or work environment are modified or improved,
- Health and safety devices, equipment and controls are modified or improved,
- Raw materials used are changed.

Once the conditions initiating management of change process are identified in the workplace, the following main questions should be asked and the answered:

- Regarding hazard identification: have new hazards been created by the changes?

- Regarding risk assessment:
    - What are the risks associated with the new hazards?
    - Have the risks from the other hazards been affected and changed?
- Regarding the risk controls:
    - Could the changes adversely affect existing risk controls?
    - Have the most appropriate risk controls been chosen considering identified changes?

As it is easily understood that management of change is one of the main subjects of not only planning process but also implementation, checking and management review processes in the OH&S management system.

4.6 Determining controls

When an organization carried out and finalized the hazard identification and risk assessment processes for its workplace, at the end, it has a comprehensive hazard list related with activities and corresponding risk values. For this moment, organization is also in the situation of having decided for any risks in its workplace whether existing controls are adequate (so risk(s) is acceptable) or need improving or if new controls are required. Where the decision of the organization is in the way of that new or improved controls are required to bring risks to the acceptable level, a further process of determining controls should be put on the agenda. This is the most important leg of the overall process, because the final aim of all the assessments carried out in the process by now, and of course, of overall OH&S management system, is just to provide a safe working workplace and minimize the risks of persons. It is clear that such a safe workplace can only be provided by determining and applying adequate controls for any risk which is not found acceptable at the end of the relevant assessments carried out.

The selection of appropriate controls is decided by the principle of hierarchy of controls. The relative cost, risk mitigation benefit and reliability of the options should be discussed as taking the hierarchy aspect into account. The hierarchy of controls can be enumerated as:

1) Elimination
2) Substitution
3) Engineering controls

4) Signage, warnings and administrative controls
5) Personal protective equipment (PPE)

If It is practicable and its cost and benefit is reasonable then the first option of control is the “elimination” of hazards altogether, e.g. modification of design, using a safe substance instead of a dangerous one, replace handling operation by mechanical lifting devices etc.

If it is not practicable and not reasonable to eliminate hazard regarding cost and benefit, then to reduce or to mitigate the risk of hazard is the second option for determining controls.

The mitigation of risk directly at source by “substitution” is the beginning control option where it is needed to reduce the risk. Reducing the system energy such as using lower the electrical voltage, lower the force, pressure, temperature etc.; introducing machinery guards; substitution a less hazardous substance instead of the others are some examples of this kind of risk controls.

“Engineering controls” such as installation of ventilation systems, sound enclosures, and interlocking systems are the controls considered where the interference at source by substitution is not practicable and reasonable.

“Signage and warnings” controls including safety signs, hazardous area signs, alarms, warning lights and sirens etc. and “administrative controls” such as preparing safety procedures, instructions, safe systems of working, making equipment inspections etc. are other typical risk controls to mitigate the risks of OH&S.

Finally supplying “personal protective equipment (PPE)” e.g. safety glasses, gloves, respirators, helmet, face shields etc. for the workforce is the another effective control to be considered to reduce the risk of hazards in the workplace.

It should be noted that legal requirements can order appropriate controls for specific hazards. In the same way, standards, codes of practice and guides may bring specifications related with adequate controls for some specific hazard. Those legal and other requirements have to be strictly applied by organizations as determining controls. Of course, in any case, for the risks which are not acceptable, the relevant control measures and necessary actions should be taken by organization to reduce

the risk to acceptable level in accordance with ALARP (as low as reasonable practicable) principle.

On the other hand, sometimes, it may be required to apply temporary controls for some activities in workplace until more effective actions are established. In such a situation, if it is necessary, system for work activity can be modified, too. Where the temporary controls are put into application, they should not be long-term and the appropriate controls should be tried to be established in shortest time.

An organization should take into consideration mainly the following items in determining controls for risks which are classified as unacceptable in the assessment:

- The need for combining elements from hierarchy of controls or a combination of controls e.g. a blend of engineering (technical) and administrative(procedural) controls,
- Established good practice in the control of particular hazard under consideration, so that risk assessment should not result to apply weaker control or to tolerate higher levels of risk than provided by the established good practice,
- Making the work adapted to persons, e.g. arranging the work appliance regarding individuals' mental and physical capabilities,
- Making usable the advantages of technical progress to improve controls,
- Trying to use control measures protecting everyone in the vicinity of a hazard in preference of protecting individuals, e.g. selecting engineering controls which protects everyone in preference to use PPE ,
- Human behavior and the discipline within the organization and whether the workforce will accept and use a particular control of risk and whether it can be effectively implemented by management,
- The need to introduce planned maintenance of, e.g. machinery safeguards,
- The possible need for emergency/contingency arrangements where risk controls fail,
- The possible need for multiple control measures,
- Basic types of human failure e.g. lapses of memory or attention, lack of understanding, error of judgment failure due to repeated action,

- The potential lack of familiarity with the workplace and existing controls of visitors, subcontractors personnel, and owner personnel etc. who are not in direct employment of the organization.

After determining controls, to prioritize the actions is an important aspect to be noted in the effective implementation of controls. Prioritizing work needed a pragmatic approach. An organization should prioritize the actions of controls in the hierarchy of:

- Their risk reductions benefits, and
- The magnitude of the risk of the activity for which they are addressed.

In this respect, the actions addressing a high risk activity or providing a substantial reduction of risk take priority in hierarchy over the actions that have only limited risk reduction benefit and addressed to a lower risk activity.

Tunneling work is a very serious construction type which involves very high hazard risks, societal risks and catastrophic hazard consequences. So establishing an effective OH&S management system and determining effective risks control measures has crucial importance for tunneling works to prevent those catastrophic consequences. In Table 4.11, hazards, probable events and proposed preventions for tunneling works are listed.

Table 4.11 Accident-Examples of cause and prevention (not in order of priority) (BS 6164:2001, pg. 6)

Accident category	Examples	Precautions and/or principal references	Other references
a) Falling from a height	Falling down shaft	Proper barriers	20.6 and 20.7
	Falling from staging at face	Secure decking; barriers where practicable	
b) Falling on the level	Tripping or slipping	Hand rails; even non-slip surface; cleaning of surface; good lighting; dedicated walkway	clause 17, clause 22
c) Materials falling from a height	Tools and small items dropped or kicked off staging or from shaft	Toe boards; proper stacking and storage; hand tools provided with thongs	20.6
	Slung loads dropped	Proper slinging and loading; loading area kept clear; see BS 7121-1 to BS 7121-5, CP 3010 and BS 4898	20.6, 21.2

Table 4.11 Accident-Examples of cause and prevention (not in order of priority)- Continued

d) Materials falling from stacks or vehicles	Collapse of stacks, e.g. timber, segments, cement bags	Proper foundation for stacks; systematic building of and maintenance of stacks	8.3.2, 20.6
	Loads falling from vehicle	Loads properly stacked and secured; level road or track well maintained	20.6
e) Burial by fall of material	Collapse of face	See clause 7 and clause 8	
	Rock falls	Barring down loose rock; immediate support	7.8
	Collapse of stacks or stockpiles	See item d)	
f) Flooding or inrush of water	Broken sewer or pipeline, groundwater, etc.	See clause 10	
g) Lifting machinery	Cranes and hoists	See clause 21	
	Hoisting and placing of segments at face	Appropriate equipment properly maintained; safest procedures enforced	8.3.2, 8.3.3
h) Other machinery	Excavating machines	Exclusion of persons from operating zone; safe procedures defined and enforced; see clause 7	
	Grouting operations	Robust equipment properly maintained; operation by trained persons; see 8.3.5	
	Conveyors	See 23.5	
i) Vehicles	Locomotives and rolling stock	See 23.1	
	Rubber-tyred vehicles	See 23.2	
j) Electrical installation	Electrocution	See clause 25	13.3
k) Fire and explosion	Burns; concussion	See clause 12, clause 13 and clause 14	11.5, 25.3.7
l) Atmospheric pollution	Atmospheric contaminants	See clause 12, clause 15 and clause 16	11.3
m) Handling materials	Lining segments; pipes	Manufacturer's guidance	8.3.2, 20.3.2, clause 21

Related with electrical works in tunnel construction; in Table 4.12 earth leakage protections to be taken into account are given regarding used circuit voltage, and in Table 4.13 the recommended mean lighting levels for a safe workplace are noted.

Table 4.12 Earth leakage protection (BS 6164:2001, pg.104)

Circuit voltage	Earth leakage protection	Time delay feature
High (1 000 V a.c. and over)	A protection device with a rated trip current not exceeding 5 A or 15 % of maximum earth fault current	No
Low (50 V a.c. to 1 000 V a.c.)	Residual current device (RCD) with a rated trip current not exceeding:	
	— 750 mA on incoming circuit	Yes
	— 300 mA for outgoing circuits to fixed equipment	Yes
	— 100 mA for mobile equipment	No
	— 100 mA for fixed lighting	No
	— 30 mA for 16 A socket outlets	No
Reduced low (110 V a.c.)	30 mA for portable lighting and hand tool	No

Table 4.13 Mean lighting levels (BS 6164:2001, pg.73)

Area	Lighting level
Walkways and tracks	10 lux at walkway level
General working areas	100 lux at working surfaces
Tunnel face Excavation areas Crane lifting points	100 lux illuminated from at least two widely separated sources to avoid shadows

In tunnel construction, fire is another source of hazard having the potential of catastrophic consequences. The initial prevention action for fire is to keep the amount of combustible material, flammable liquid and compressed gas in the tunnel to a minimum. Besides that, suitable fire-fighting equipments should be located conspicuously nearby where combustible materials stored in the tunnel. Table 4.14 shows the suitable fire extinguishing equipment and the required extinguishing

medium regarding the location of fire. Additionally, Table 4.15 gives information about use of portable fire extinguishing equipment.

Table 4.14 Provision of fire extinguishing equipment (BS 6164:2001, pg.54)

Location of fire	Extinguishing medium				
	Water (jet)	Water (spray)	Foam	Inert gas	Powder
Tunnel — general	F		P	P	P
TBM — general			P	P	P
TBM — hydraulics			F		F
TBM — electrics				F	F
Diesel plant			F		F
Battery locomotives				F	F
Fuel store			P		P
Battery charging					P
Compressed-air workings	F	F	P		
Timber headings, break-outs, etc.	F		P		
F = Fixed , P = Portable					

Table 4.15 Portable fire extinguishing equipment (BS 6164:2001, pg.55)

Class of materials involved	Extinguishing medium
Fires involving solid usually of an organic nature, in which combustion normally takes place with the formation of glowing embers	Water extinguisher
Fires involving liquids or liquefiable solids	Foam extinguisher, CO2, dry powder
Fires involving gases	Water spray to cool cylinder, foam to extinguish any fire when valve has been closed
Fires involving metals	Dry powder, dry sand
Electrical equipment (if live)	Inert gas, dry powder, dry sand

4.7 Recording and documenting the results

The organization should document and keep the results of hazard identification, risk assessment and determining controls processes. The records should enable the organization to demonstrate systematically all identified hazards, evaluated risk values and determined adequate controls.

In BS 8800:2004, to record the results of the overall process, a simple pro-forma covering typically the following aspects is recommended:

- Area under consideration,
- Work activity,
- Existing controls in place,
- Employees at risk,
- Likelihood of harm,
- Severity of harm,
- Risk levels and their tolerability (whether acceptable or not),
- Action to be taken following the assessment(determining controls), including the action owner, target date for completion, prioritization category for the action,
- Risk levels after implementation of those actions, including changes to risk controls and the tolerability of the resulting risks,
- Any significant assumption made in the assessment(overall process),
- Administrative details e.g. name of assessor, other people consulted during the assessment (overall process), reviewers, endorsement by accountable manager, date of assessment, date by which the assessment should be reviewed.

This documentation prepared subsequent to the overall process of hazard identification, risk assessment and determining controls is named as “risk register” and described as the document summarizing clearly and concisely how risks are to be allocated, controlled, mitigated and managed, by The Joint Code of Practice for Risk Management of Tunnel Works in UK: 2003 BTS (The British Tunneling Society), ABI (The Association of British Insurers).

4.8. Implement controls, monitor and review

Hazard identification, risk assessment and determining controls processes as an overall process is the part of a continual process. So subsequent to the overall process, “the implementation of controls” and “monitoring & reviewing” processes should be established in the OH&S management system. Furthermore, “implementation of controls” and “monitoring & reviewing” together with “hazard identification, risk assessment and determining controls” process need periodic formal reviews and checking by internal audits to confirm the validity of the assessment (overall process) and whether risk controls are still effective.

“Implementation of controls” and “monitoring & reviewing” processes are, in fact, the subjects of “implementation”, “checking” and “management review” main processes in the OH&S management system. So they are not in the scope of this study and it will not be entered further explanation here but the short note above.

CHAPTER 5

THE CASE STUDY OF MARMARAY PROJECT

5.1 General

The Marmaray Project which is the subject of the case study in the thesis is one of the major transportation infrastructure projects in Turkey; in fact one of the most interesting projects in the world. The complete name of the project is “the Marmaray Rail Tube Tunnel and Commuter Rail Mass Transit System in Istanbul”. But it is generally called, in short, as the Marmaray Project, and in the study this tradition will be maintained.

The aim of the Marmaray project is to provide a long-term solution to the transport problems of Istanbul city by a railway connection between Europe and Asia sides by crossing Istanbul Strait. While the number of passengers per hour with existing railway – ferry – railway transport is 10.000, it will be increased to 75.000 passengers per hour by the Marmaray Project. Besides that, it will shorten the travel time of 1 million people per day, and hence will bring important savings in time and energy. The Marmaray project will help to reduce the traffic density on the existing bridges, too.

The responsible ministry of the project is “Ministry of Transportation”, and “General Directorate of Railways, Harbours, and Airports Construction”, the DLH, is the responsible directorate for implementation of the project as employer.

Avrasya Consult is representative of the employer, the DLH. It is a joint venture constituted by;

- Oriental Consultants, the lead partner from Japan,
- Yüksel Proje Uluslararası A.Ş.,from Turkey
- JARTS, from Japan

The Marmaray project composed of three parts;

- “Contract BC1” : Railway Bosphorus Tube Crossing, Tunnels and Stations Construction,
- “Contract CR1”: Gebze-Haydarpaşa, Sirkeci-Halkalı Commuter Rail; Civil & Electrical & Mechanical Systems,
- “Contract CR2”: Rolling Stock Production.

5.2 Contract BC1

Contract BC1 is the most important part of the Marmaray Project. It involves

- Immerse tube tunnel work of 1387 m crossing Istanbul strait and connecting Europe and Asia sides of Istanbul,
- Five stations construction in which there are three underground and two at level grade stations,
- 2x9,897m bored tunnel construction which is the part of total 13,576 underground alignment.

Those works including immersed tunnel, NATM (New Austrian Tunneling Method) tunnels, bored tunnels and cut-and-cover stations construction under Contract BC1 are communicated as CST works in short.

Contract BC1 is undertaken by TGN JV with a lump-sum fixed price under FIDIC 1999 1.Edition conditions for the both of design and construction works. .

TGN JV is established as a joint venture by three famous and high experienced international construction companies:

- Taisei Corporation, the lead partner from Japan
- Gama Endüstri Tesisleri İmalat Montaj A.Ş., from Turkey
- Nurol İnşaat ve Ticaret A.Ş., from Turkey

Contract BC1 is signed in June 2004 and sites handed over to TGN JV in August 2004. The original work completion time was April 2009, and it has been extended to October 2013, especially by the reason of archeological requirements and studies which has taken much more time than programmed and expected.

Figure 5.1 A Schematic alignment for Marmaray Project Contract BC 1 on Istanbul Map

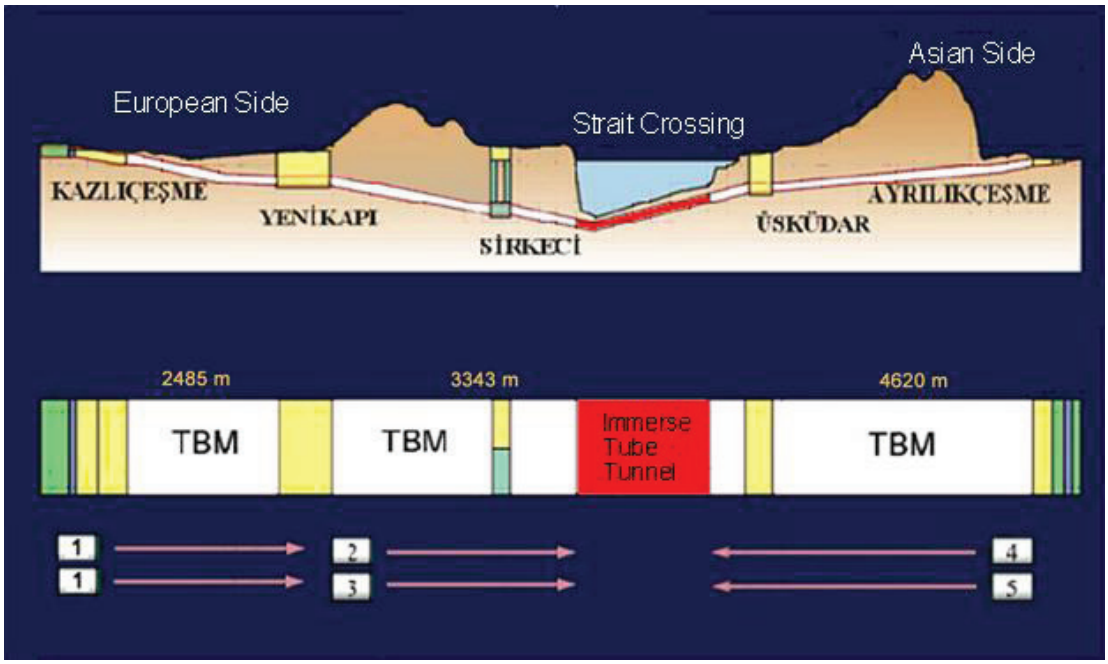


Figure 5.2 A Schematic Section for Marmaray Project Contract BC 1

5.3 Allocation of construction works between partners of TGN JV

The construction works allocated to the lead partner of the TGN JV are:

- The immerse tube tunnel work of 1387 m crossing crossing Istanbul strait between Sirkeci (Sarayburnu) and Üsküdar,
- All NATM (New Austrian Tunneling Method) tunnels and the parts of stations constructed by NATM method (e.g. Sirkeci Station Construction),
- Bored tunnels between Ayrılıkçeşme - Üsküdar sea front of 2x4210 m and Yenikapı - Sarayburnu of 2x3072 m which are all drilled with closed-face shield TBM with slurry (TBM-Slurry).

On the other hand construction works of:

- Bored tunnel between Yedikule – Yenikapı of 2x 2480 m which is drilled by the closed-face shield TBM with earth pressure balance (EPB – TBM),
- Four stations which are Kazlıçeşme, Yenikapı, Sirkeci Stations at European side and Üsküdar, Ayrılıkçeşme Stations at Asian side of Istanbul,

are undertaken by the other two partners of TGN JV, Gama A.Ş.and Nurol A.Ş.

Gama A.Ş. and Nurol A.Ş. companies established a consortium between them to carry out the construction works under their responsibilities. The organization constructed for this purpose is called GN Organization in the current correspondence between the parties of the Marmaray project and so in this study.

5.4 Constructions and the organization in the scope of the case study

The scope of the case study in this thesis is limited with the OH&S application of GN organization. The OH&S application of Taisei Corporation for the construction works under its duty is not involved in it.

GN organization installed 6 discriminated Construction Sites. They are from west to east:

- Kazlıçeşme Station Construction Site,
- Yedikule EPM TBM Tunneling Construction Site,

- Yenikapı Station Construction Site,
- Sirkeci Station Construction Site,
- Üsküdar Station Construction Site,
- Ayrılıkçeşme Station Construction Site.

Sirkeci Station construction is mostly implemented by NATM (New Austrian Tunneling Method) and so by Taisei Corp.The remain Cut-and-Cover construction works is executed by Sirkeci Station Construction Site management of GN Organization.

Kazlıçeşme Station is at grade station and constructions managed by Kazlıçeşme Construction Site Organization.

Ayrılıkçeşme Station is another at grade level station, but it does not have a separate construction site management and it is administrated by Üsküdar Construction Site Organization.

Sirkeci Station, Kazlıçeşme Station and Ayrılıkçeşme Station constructions are held out of the scope of the case study.

Yenikapı Station and Üsküdar Station are fundamental underground station construction implemented by cut-and-cover method from the top to down in the Marmaray Project and they have their own Construction Site Organizations.

The two stations, Yenikapı and Üsküdar Station, are both worth to be in the scope of the case study. But in the period of investigations carried out at construction sites, it is realized that taking the both of these cut-and-cover stations construction in the scope the case study would be a repetition and loading the thesis in vain.

However, Üsküdar Station construction is really a substantial construction work for a cut-and-cover underground station construction regarding it size and conditions. In this respect, it is 278 m in length, 32 m in width, 30 m in depth under the sea level and it is just at the sea side. So OH&S application for Üsküdar Station Construction is preferred to be included in the scope of the case study as the example of cut-and-cover underground stations construction in the Marmaray Project.

The bored tunnel construction between Yedikule–Yenikapı of 2x2480 m implemented by closed-face shield TBM with earth pressure balance (EPB – TBM) is the other OH&S application place worked in the scope of the case study. It is

executed by Yedikule Construction Site of GN Organization and is taken as the example of OH&S application for tunnel construction in the Marmaray Project.

For the update, GN Organization has spent approximately 4 million man-hours as direct and 7 million man-hours as indirect workforce. On the other hand, 73% of the overall work under GN Organization duty is realized by now.

5.5 OH&S management system of TGN Organization

A succinct explanation is given in subsequent sections about the application of TGN Organization for some main items of OH&S management system which are nearly related with the subject of the study.

5.5.1 OH&S Policy of TGN Organization

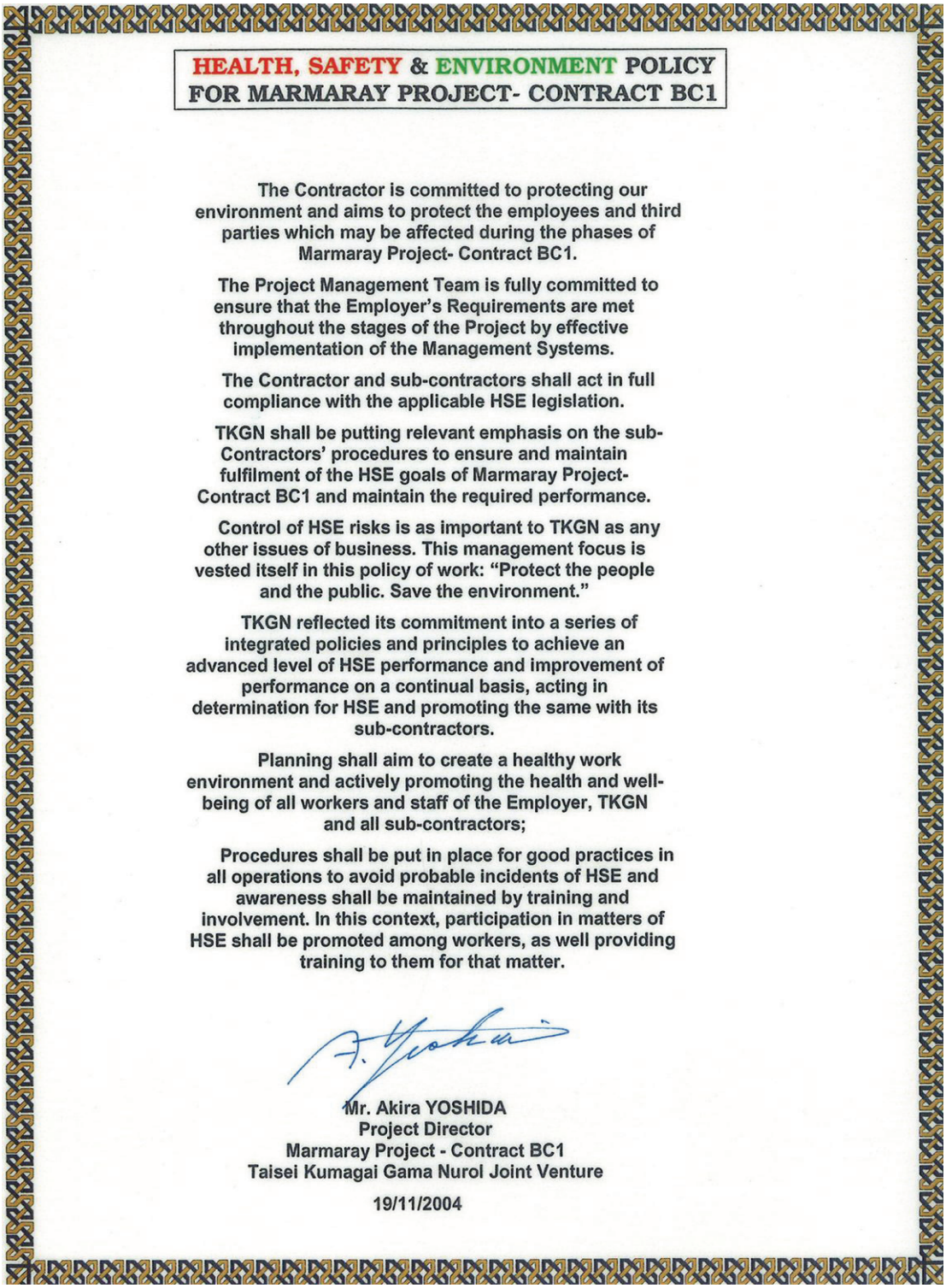
OH&S Policy of TGN Organization (including environment) is signed and declared by top management. This declaration is shown as it is in Figure 5.3 in the next page.

5.5.2 OH&S objectives and targets of TGN Organization

5.5.2.1 OH&S Objectives

The fundamental OH&S Objectives of TGN Organization throughout the Project are:

1. Saving the Environment,
2. Protecting employees and public,
3. Complying with the Employer's Requirements,
4. Complying with the applicable Turkish OH&S Legislation,
5. Evaluating and improving OH&S Performance,
6. Minimizing OH&S Hazards,
7. Controlling and monitoring adverse OH&S Impacts/Risks,
8. Getting ready and responding immediately for Emergencies,
9. Achieving prevention of pollution,
10. Ensuring subcontractors comply with the Contractor's OH&S Management System,
11. Applying best practices for closing out non-conformances on OH&S Management System,
12. Training employees and informing relevant parties on OH&S.



HEALTH, SAFETY & ENVIRONMENT POLICY FOR MARMARAY PROJECT- CONTRACT BC1

The Contractor is committed to protecting our environment and aims to protect the employees and third parties which may be affected during the phases of Marmaray Project- Contract BC1.

The Project Management Team is fully committed to ensure that the Employer's Requirements are met throughout the stages of the Project by effective implementation of the Management Systems.

The Contractor and sub-contractors shall act in full compliance with the applicable HSE legislation.

TKGN shall be putting relevant emphasis on the sub-Contractors' procedures to ensure and maintain fulfilment of the HSE goals of Marmaray Project-Contract BC1 and maintain the required performance.

Control of HSE risks is as important to TKGN as any other issues of business. This management focus is vested itself in this policy of work: "Protect the people and the public. Save the environment."

TKGN reflected its commitment into a series of integrated policies and principles to achieve an advanced level of HSE performance and improvement of performance on a continual basis, acting in determination for HSE and promoting the same with its sub-contractors.

Planning shall aim to create a healthy work environment and actively promoting the health and well-being of all workers and staff of the Employer, TKGN and all sub-contractors;

Procedures shall be put in place for good practices in all operations to avoid probable incidents of HSE and awareness shall be maintained by training and involvement. In this context, participation in matters of HSE shall be promoted among workers, as well providing training to them for that matter.

Mr. Akira YOSHIDA
Project Director
Marmaray Project - Contract BC1
Taisei Kumagai Gama Nurol Joint Venture

19/11/2004

Figure 5.3 OH&S Policy declared by TGN Organization

5.5.2.2 OH&S Targets

The HSE (including environment) targets of TGN Organization related with its objectives noted in the prior section by the end of 2006 are:

1. Monitoring amendments on relevant/applicable HSE Legislation periodically,
2. No significant environmental incidents,
3. Target rate for fatalities shall be zero (Number of fatalities per one million working man-hours shall not exceed 0.075),
4. Raising the collection ratio for used papers, cardboards, plastics and metals (80 kg to 100 kg as monthly basis) for recycling,
5. No degradation to the nature of Bosphorus fauna,
6. Raising HSE training hours per capita-month from 0.5 up to 1,
7. Raising the number of HSE training sessions given to workforce,
8. Conducting emergency response drills / exercises periodically for work sites,
9. Raising the number of HSE inspections per month from 30 up to 45,
10. Raising the number of HSE audits,
11. Responding major HSE non-conformities using best practices not later than 2 days,
12. Reducing the Days Away From Work Cases (DAFWC) per month from 7 to 5,
13. Reducing the number of incidents per month from 10 to 5,
14. Reducing the number of complaints per month from 3 to 1,
15. Raising the number of awarded employees within the Safety Incentive Programs.

5.5.3 OH&S Organization

OH&S management system of TGN Organization has been established as a part of an integrated Quality and HSE (Health, Safety and Environment) management system. The Organization constructed to perform OH&S (HSE) management system has two main parts. The one is the top organization, called TGN JV Organization, including also the top manager of CST works division. This top organization is, at the same time, the authority which provides coordination with the employer, the DLH, and its representative, Avrasya Consultant. The second part of the organization is CST works division and it is in fact coincides with GN Organization. The OH&S (HSE) management system of TGN Organization is implemented and monitored under the coordination of these two sub organizations.

The chart for total Quality and HSE (including environment) Management System of TGN Organization is shown in Figure 5.4.

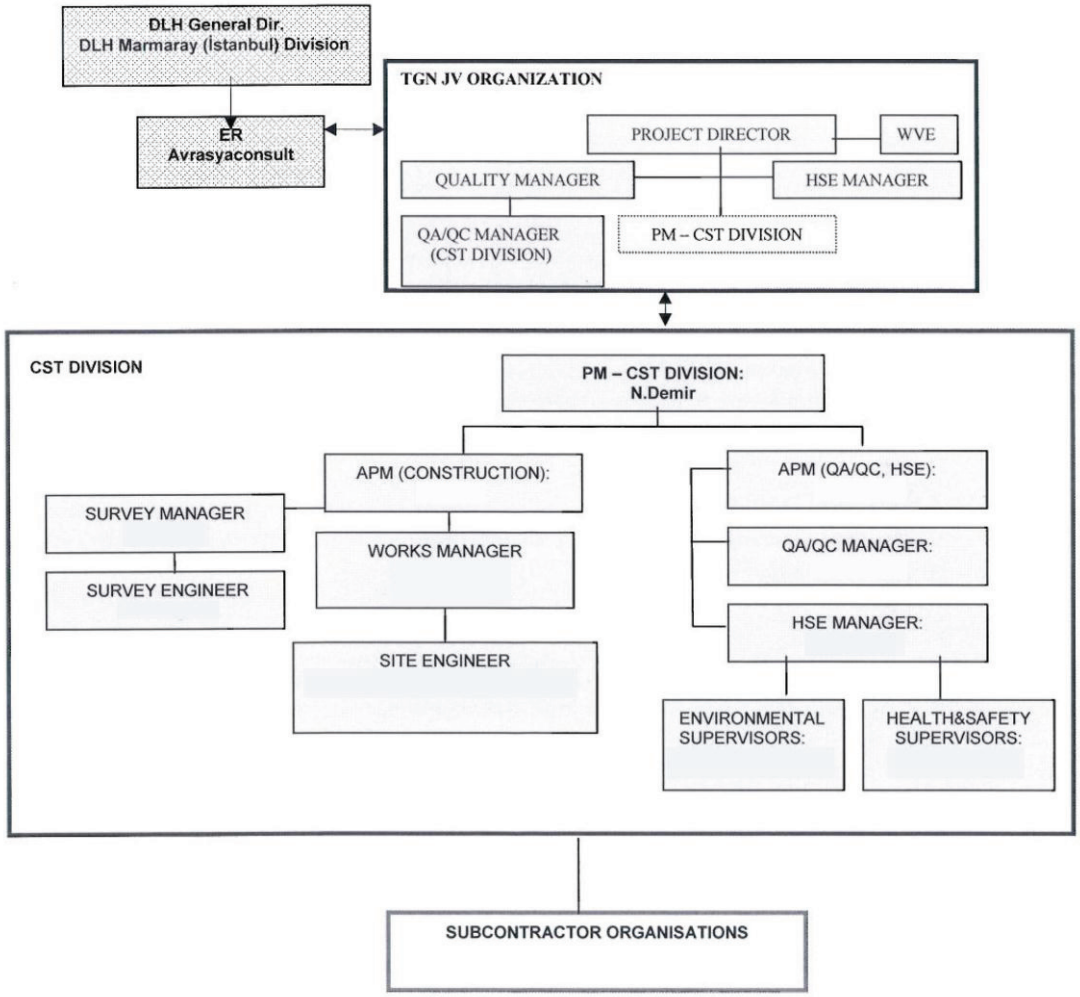


Figure 5.4 Integrated Quality and HSE Management System organization structure of TGN Organization

5.5.4 Standards, Codes of practice, Legislation to be followed

TGN organization is required to be complied with the principles of the standards, guidance, codes of practice given below in due of its contract with the Employer:

- Applicable national legislation
- OHSAS 18001: Occupational Health and Safety Assessment Series-Occupational health and safety management systems-Requirements
- OHSAS 18002 : Occupational Health and Safety Assessment Series-Occupational health and safety management systems-Guidelines for the implementation of OHSAS 18001

- The Construction (CDM) Regulations 2000
- BS 6164: Code of Practice for safety in Tunneling in the Construction Industry

The hierarchy of OH&S documentation complied by TGN organization is shown in Figure 5.5 below, as given in the OH&S Manual:

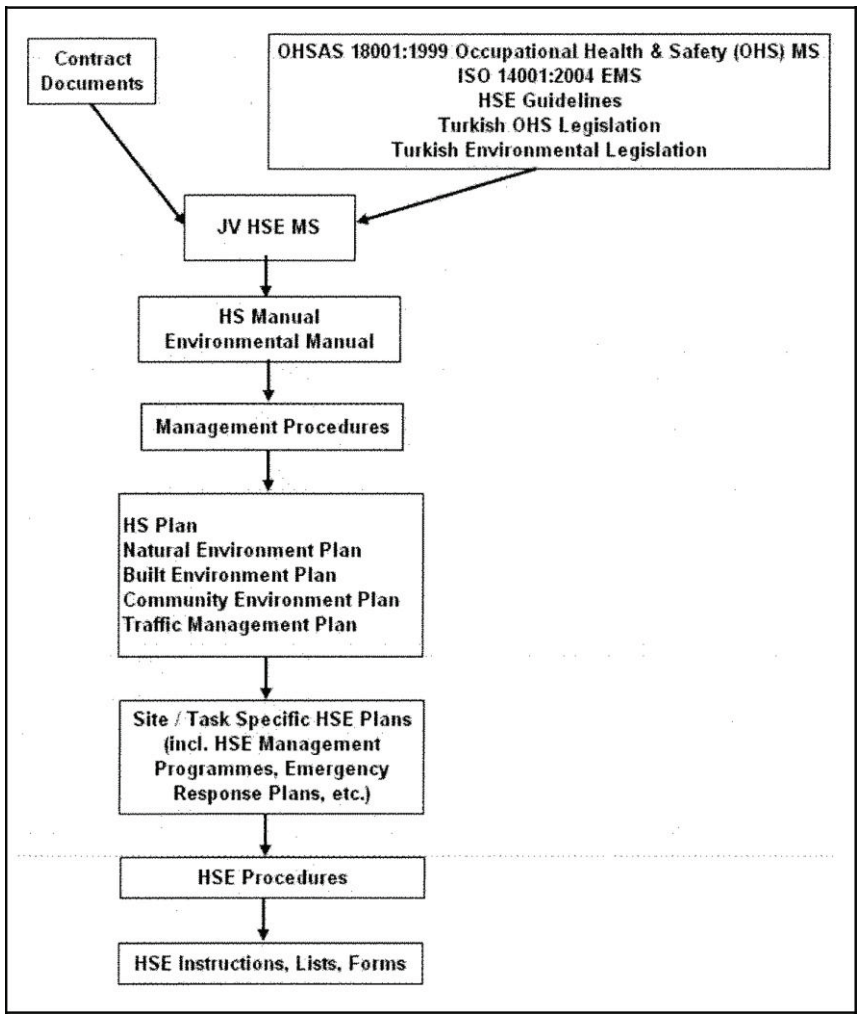


Figure 5.5 The hierarchy of OH&S documentation

The applicable laws and regulations in the mean of national legislation with which TGN Organization has the strict compliance are listed in Table 5.1 in the following page.

Table 5.1 OH&S Regulatory List (National Legislation) of TGN Organization

Laws, Regulations, Statements	Official Gazette	Date
Labour Law (No:4857)	25134	6/10/2003
Bylaw for Occupational Health & Safety	13435	3/3/1970
Bylaw for Occupational Health & Safety Precautions Taken at Mineral & Stone Mine Establishments and Tunnelling Works	18553	10/22/1984
Regulation on Occupational Health and Safety	25311	12/9/2003
Regulation on Responsibilities; and Working Procedures and Principles for Occupational Health Unit and Occupational Doctors	25318	12/16/2003
Regulation on Health and Safety Precautions for Work With Display Screen Equipment	25325	12/23/2003
Regulation on Noise	25325	12/23/2003
Regulation on Vibration	25325	12/23/2003
Regulation on Health and Safety Requirements at Construction Sites	25325	12/23/2003
Regulation on Health and Safety Signs at Workplaces	25325	12/23/2003
Regulation on Health and Safety Precautions for Exposure to Asbestos at Work	25328	12/26/2003
Regulation on Health and Safety Precautions for Chemicals at Work	25328	12/26/2003
Regulation on Responsibilities; and Working Procedures and Principles for Occupational Safety Engineer or Technician	25352	1/20/2004
Regulation on Safety and Health Requirements for the Use of Work Equipment	25370	2/11/2004
Regulation on Personal Protective Equipment	25368	2/9/2004
Regulation on Health and Safety Precautions at Workplace Building and Accessories	25369	2/10/2004
Regulation on the Use of Personal Protective Equipment at Workplaces	25370	2/11/2004

Table 5.1 OH&S Regulatory List (National Legislation) of TGN Organization - Continued

Laws, Regulations, Statements	Official Gazette	Date
Regulation on Recruitment of Handicapped, Formerly Convicted and Terrorly Mistreated Persons	25412	3/24/2004
The Decision of the Council of Ministers about Recruitment of Handicapped, Formerly Convicted and Terrorly Mistreated Persons	2005/9077	7/8/2005
Regulation on Working Hours Regarding Labour Law	25425	4/6/2004
Regulation on Overtime Work and Emending the Overtime Regarding Labour Law	25425	4/6/2004
Regulation on Procedures and Principles for Occupational Health & Safety Trainings	25426	4/7/2004
Regulation on Occupational Health and Safety Committee	25426	4/7/2004
Regulation on Working Time Restricted with Maximum 7 ½ hours or less per day due to Health Care Conditions	25434	4/15/2004
Regulation on Hard and Dangerous Works	25494	6/16/2004
Regulation on Establishment of Work Office and Operating Licence	25673	12/17/2004
Rules on Occupational Health and Safety Risk Group List	25747	3/6/2005

5.6 Hazard identification, risks assessment and determining controls processes in GN Organization for cut-and-cover stations and tunnel construction

5.6.1 Methodologies followed by GN Organization

5.6.1.1 Methodology followed for hazard identification

The methodology used for hazard identification is based on the mainly past experience of GN Organization, participation and consultation of workforce, experience of subcontractors and other organizations' experience performed similar projects. Recommendations of codes of practice, guidelines and documentations published by competent agencies related with carried works, e.g. tunnel construction etc., are the other sources conformed by the Organization. For hazard identification purpose, a multidisciplinary team is incited who are competent in their scope and hence a HAZID (hazard identification) workshop started to run from the beginning of the contract. In HAZID workshop, the works which have to be performed to realize the construction project, are itemized and then sub-itemized in a chain order for deduction of hazard which is hazardous source, situation, act or a combination of these in definition. It is to say, in HAZID workshop, the steps of the construction are determined and hence main "works" are defined firstly, and then "main activities" required to perform each main work, and then the "activities" for each main activity. By this work analysis, at the end, the hazard (process) arising from each class of work - each main activity - each activity which constitute a row of activity is identified. HAZID workshop performed work-activity analysis on all stations and tunnel construction and hence identified all processes (hazards) covering overall the project in the meaning of cut-and-cover stations and tunnel construction and finally a specific prompt list of process (hazard) is established.

In Table 5.2 prompt list of process (hazard) constructed by HAZID workshop is given (see the next page).

HAZID workshop, subsequent to hazard identification, also executed a root cause analysis for each process (hazard) and so, made prediction for hazard initiating events, determined top events and consequent risk such as fatality or injury for each identified hazard.

In the case study, the application of hazard identification process, is presented in the topics of "Activity analysis and hazard identification" and "Hazard event analysis" for

Üsküdar Station and “Activity & event analysis and hazard identification” for EPB TBM tunnel construction.

Table 5.2 Prompt list of process (hazard) constructed by HAZID Workshop

No	Work Process	Abbreviations
1	Demolition	DMLISH
2	Earthworks	EARTH
3	Construction Equipment	EQUIP
4	Moving Machinery	MACH
5	Tools	TOOL
6	Lifting	LIFT
7	Work at height	HGHT
8	Electrical works	ELECT
9	Hotwork	HOTW
10	Compressed air	COMP
11	Manual handling	MANUAL
12	Work with chemicals	CHEMIC
13	Road Traffic	TRFC
14	Confined space	CONF
15	TBM/Tunneling	TUNN
16	Pressure vessels	PRESS
17	Archeological explorations	ARCH
18	Diving	DIVE
19	Radiographic works	RADIA

The classification of incidents studied by HAZID workshop is shown in Figure 5.6 in the next page.

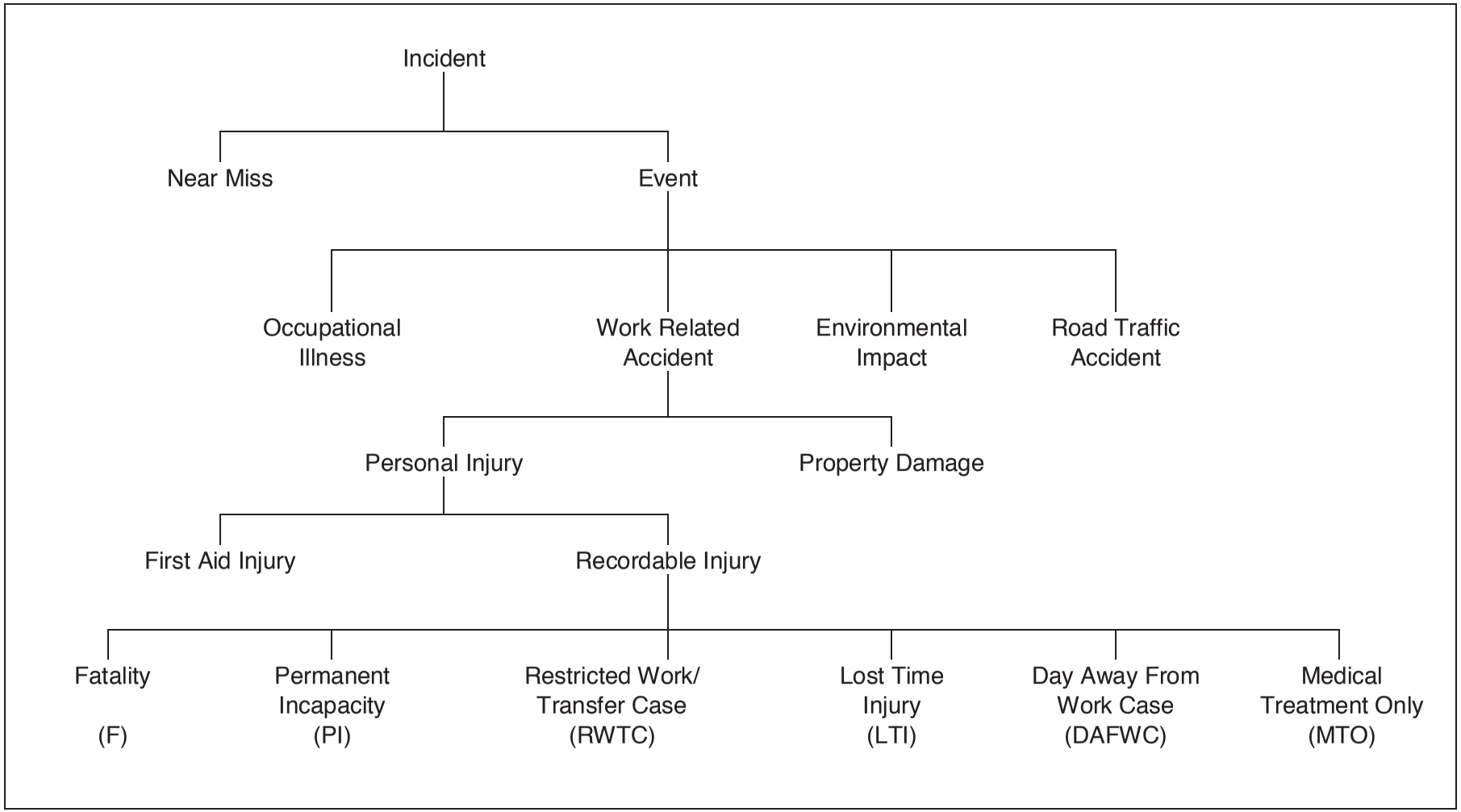


Figure 5.6 Classification of incidents studied by HAZID workshop

5.6.1.2 Methodology followed for risk assessment

5x5 risk matrix methodology is followed in risk assessment process. After identification of hazards, the frequency (likelihood) of hazardous event, and its severity of consequence are assessed in the five categories determined by 5x5 risk matrix methodology and corresponding quantitative values are appointed and hence risk value or level is estimated for each hazard. Then, regarding the risk value estimated, it is assessed whether the risk level is acceptable or not under existing risk control measures. This assessment provides, at the same time, the base to decide whether it is needed to reduce the risk level and accordingly to apply further control measures.

Risk assessment process is repeated and risk levels are estimated again for the conditions after mitigation by the same method of analysis and then it is checked whether the risk level is reduced to acceptable category or not.

An exhaustive explanation of 5x5 risk matrix methodology is given in Section 5.6.2 under separate heading.

5.6.1.3 Methodology followed for determining controls

As in hazard identification, the method used in determining controls process is also based on the mainly past experience of GN Organization, participation and consultation of workforce, experience of subcontractors and other organizations' experience performed similar projects. Legal requirements for specific hazards are strictly taken into account in the meaning of determining controls. Requirements from standards, codes of practice, guidelines related with carried works, e.g. tunneling works etc., are also taken into account in the application. The commitment of top management which is declared in OH&S Policy, Objectives and Targets are implemented carefully as requirements subscribed by TGN Organization. HAZID (hazard identification) workshop established required control measures and proposed actions for each hazard regarding the results of risk assessment process to reduce the risk categories to acceptable levels in accordance with ALARP (as low as reasonably possible) principle, legal requirements and other requirements including standards, codes of practices, guides and subscribed by TGN Organization. Besides that, all the proposed actions to reduce the risks are addressed to related parties.

The criteria behind the determining control measures followed by GN organization can be best explained by the help of Figure 5.7 and Table 5.3. For the terminology and information used in Figure 5.7 and Table 5.3 related with risk, it would be better to look at "Section 5.6.2 Application of 5x5 risk matrix methodology in risk assessment".

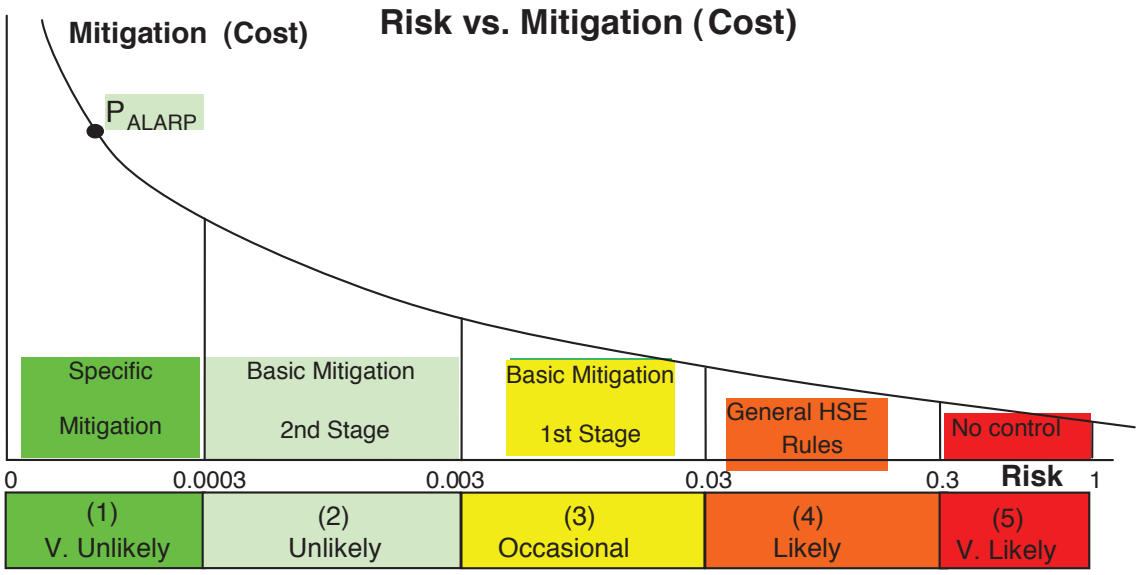


Figure 5.7 Risk-Mitigation (cost) relationship (Demir, N.: 2008)

Where;

"Basic Mitigation Measures -1st Stage" are those required in accordance with the current legislation and the terms of contract,

"Basic Mitigation Measures - 2st Stage" are those in accordance with special standards and codes applicable to the work,

"Specific Mitigation Measures" are additional measures to be defined on the basis of a specific risk assessment in order to reduce the residual risks in accordance the ALARP principle.

Table 5.3 Proposed risk acceptance, risk mitigation and risk management criteria

Risk Level	Risk Class	Action	
		Risk Mitigation	Risk Management
1,0-2,9	Negligible	None	None
3,0-4,9	Acceptable	None	Yes
5,0-12,9	Unwanted	Acceptable/ALARP[1,2]	Yes
13,0-25,0	Unacceptable	Acceptable/ALARP[1,2]	Yes
(1) Risk mitigation as per ALARP Principle for risks involving fatality (2) The number of fatalities per one million man-hours shall not exceed 0,075			

Preparation of management and technical procedures for process control to provide a safe workplace should have a crucial importance in mitigation approach of an organization. The list of procedures established by TGN Organization is noted in Table 5.4 in the next page to give an idea about TGN Organization's approach to OH&S risk control or risk mitigation matter.

5.6.1.4 Risk registers

When hazard identification, risk assessment and determining controls processes are carried out and finalized by HAZID workshop, the results are recorded for each construction site and construction phase to enable to demonstrate systematically all identified hazards, root causes in the meaning of initiating events, sources of event, top events; evaluated risk values, risk classes before and after mitigation and determined adequate controls and proposed actions to reduce the risk to acceptable level as addressed to owner and in due party. Risk Registers and Risk Sub-Registers are established as result of such a recording system and it is participated by the organization and the Employer. Risk Register tables are the basic and fundamental documents of identified hazards, risks assessed and relevant controls and actions to mitigate the risks to acceptable levels for the construction under consideration. In this respect, Risk Registers are based in preparing OH&S management sections of CIQP's (Construction and Installation Quality Plan) and Method Statements. For establishing Specific Task RAMP's (Risk Assessment and Mitigation Plan) which are needed at different stages of the construction, Risk Registers are needed again as the basic documentation of OH&S management system.

Table 5.4 HSE Procedures List for CST works

BC1-PR-HSE-30	Procedure for Evaluation of HSE Management System Performance
BC1-PR-HSE-31	TGN Environmental – Waste Water Discharge Procedure
BC1-PR-HSE-32	TGN Environmental - Solid Waste Management Procedure
BC1-PR-HSE-33	TGN Environmental Complaint and Suggestion Procedure
BC1-PR-HSE-34	TGN Spill Response Procedure
BC1-PR-HSE-40	TGN HSE - Air Pollution Control Procedure
BC1-PR-HSE-41	TGN HSE - Noise and Vibration Control Procedure
BC1-PR-HSE-42	TGN HSE Audit and Inspection Procedure
BC1-PR-HSE-43	TGN HSE Communication Procedure
BC1-PR-HSE-44	TGN HSE Corrective and Preventive Action Procedure
BC1-PR-HSE-45	TGN HSE Procedure for Preparation of Emergency Preparedness and Response Plan
BC1-PR-HSE-46	TGN HSE Incident Management Procedure
BC1-PR-HSE-47	TGN HSE Painting, Coating and Sand Blasting Procedure
BC1-PR-HSE-48	TGN HSE Subcontractor HSE Management Procedure
BC1-PR-HSE-49	TGN HSE Training Procedure
BC1-PR-HSE-50	TGN HSE Procedure for Demolition Safety
BC1-PR-HSE-51	Procedure for Archaeological Works
BC1-PR-HSE-52	TGN HSE – General HSE Rules Procedure
BC1-PR-HSE-54	TGN HSE – Procedure for Regulatory Compliance
BC1-PR-HSE-60	TGN HS - Excavation Procedure
BC1-PR-HSE-61	TGN HS - Compressed Air Procedure
BC1-PR-HSE-62	TGN HS - Permit to Work Procedure at Confined Spaces
BC1-PR-HSE-63	TGN HS – Construction Machines, Equipment and Machine Guard Procedure
BC1-PR-HSE-64	TGN HS – COSHH Procedure
BC1-PR-HSE-65	TGN HS – Diving Safety Procedure
BC1-PR-HSE-66	TGN HS – Electrical Safety Procedure
BC1-PR-HSE-67	TGN HS – Fire Safety Procedure

Table 5.4 HSE Procedures List for CST works – Continued

BC1-PR-HSE-68	TGN HS – Lifting Operation Procedure
BC1-PR-HSE-69	TGN HS – Medical, Welfare and Hygiene Procedure
BC1-PR-HSE-71	TGN HS – PPE Procedure
BC1-PR-HSE-72	TGN HS – Pressurized Vessels Procedure
BC1-PR-HSE-73	TGN HS – Radiographic Works Procedure
BC1-PR-HSE-74	TGN HS – Safety Incentive Procedure
BC1-PR-HSE-75	TGN HS – Safety Signs and Signals Procedure
BC1-PR-HSE-76	TGN HS – Transportation Procedure
BC1-PR-HSE-77	TGN HS – Welding, Cutting and Grinding Procedure
BC1-PR-HSE-78	TGN HS – Security Procedure
BC1-PR-HSE-79	TGN HS – H&S Committee Procedure
BC1-PR-HSE-80	TGN HS – Working at Height and Scaffolding Procedure
BC1-PR-HSE-81	TGN HS – Safety at Tunnelling
BC1-PR-HSE-82	TGN HS – Visitors Control Procedure for Work Site
BC1-PR-HSE-83	TGN HS – Procedure for NATM Shaft and Tunnel Entry
BC1-PR-HSE-84	TGN HS – Safe Working Procedure for Immersed Tube Tunnel Construction

5.6.2 Application of 5x5 risk matrix methodology in risk assessment

GN organization uses 5x5 risk matrix methodology in risk assessment process i.e. in the evaluation of risk values, classifying risks and deciding whether or not risks are acceptable. Matrix method in risk assessment is a semi-quantified way of evaluation. Risk value is determined by estimating of the potential severity of hazardous event and the likelihood that it will occur. Risk value is formulated as:

$$R = P \times S$$

Where:

P = Likelihood of occurrence

S = Potential severity of harm

Risk matrix methodology approach is based on mainly developing a series of categories for severity and likelihood of harm, in the purpose of enabling the comparable events to be grouped and assessed together. Therefore, main skeleton of risk matrix methodology is constituted by frequency classification (categories for likelihood of harm), consequence classification (harm categories) and risk classification (category of risk). Those three categories are interrelated and a risk matrix is established as result. Risk classification can be on the basis of risk level (value) and/or risk acceptance. Of course, this makes also possible to establish simply direct relation between category of risk based on risk level and risk category based on risk acceptance. 5x5 risk matrix methodology defines 5 classes of frequency and 5 classes of consequence and makes these classifications both in descriptive and quantitative features. In this respect, each descriptive class for frequency and consequence has a corresponding quantitative value from 1 to 5. Risks are evaluated by multiplying those values for frequency and consequence, and as the result, risk values of from 1 to 25 are produced in the combination of different categories of frequency and severity of consequence.

All those steps are tried to explain in the subsequent parts by the helps of tables and matrices.

5.6.2.1 Categories for likelihood of harm (Frequency classification)

Five categories described by risk matrix methodology are:

- Very likely (quantitative value : 5)
- Likely (" " : 4)
- Occasional (" " : 3)
- Unlikely (" " : 2)
- Very unlikely (" " : 1)

Table 5.5 shows frequency of occurrence in the base of construction period and determines their correspondence with both descriptive and quantitative frequency classes. While Table 5.6 gives another approach to determine descriptive category of likelihood of harm by corresponding the number occurrence of hazardous event for 4 folds (bands) classification.

Table 5.5 Frequency of occurrence (in the construction period) (Eskesen, S.D., Tengborg, P., Kampmann, J., Veicherts T.H:2004, ITA, pg.225)

Frequency Class	Interval	Central Value	Descriptive Frequency Class
5	>0.3	1	Very likely
4	0.03 to 0.3	0.1	Likely
3	0.003 to 0.03	0.01	Occasional
2	0.0003 to 0.003	0.001	Unlikely
1	<0.0003	0.0001	Very unlikely
Note **:** The central value represents the logarithmic mean value of the given interval.			

Table 5.6 Examples of categories for likelihood of harm (BS 8800:2004, pg.48)

Categories for Likelihood of Harm	**Very Likely**	**Likely**	**Unlikely**	**Very Unlikely**
Typical occurrence	Typically experienced at least once every six months by an individual	Typically experienced once every five years by an individual	Typically experienced once during the working lifetime of an individual	Less than 1 % chance of being experienced by an individual during their working lifetime

5.6.2.2 Harm categories for severity of harm (Consequence classification)

Defined five harm categories are:

- Disastrous (quantitative value : 5)
- Severe (" " : 4)
- Serious (" " : 3)
- Considerable (" " : 2)
- Insignificant (" " : 1)

Table 5.7 shows a consequence classification as descriptive and quantitative, defined according to, e.g. for injuries to workers and third parties and occurrences of harm severity as fatality, serious injury and minor injury (in this classification, an underground construction project with a project value of approximately 1 billion Euro and duration of approximately 5-7 years is taken consideration).

Table 5.7 Consequence classification (Skeen, S.D., Tengborg, P., Kampmann,J., Veicherts T.H. : 2004, ITA, pg.226,227)

No	Consequence	Severity of Consequence				
		Disastrous	**Severe**	**Serious**	**Considerable**	**Insignificant**
		5	**4**	**3**	**2**	**1**
1	Injury to Employee	F>10	1<F≤10	1 F		
			SI> 10	1<SI ≤10	1 SI	
					1<MI ≤10	1 MI
2	Injury to 3. party	F>1	1 F			
		SI > 10	1<SI ≤10	1 SI		
				1<MI ≤10	1 MI	
3	Environment	Permanent severe damage	Permanent minor damage	Long-term effects	Temporary severe damage	Temporary minor damage
4	Damage to property[1]	>3 mio €	3-0.3 mio €	30 000- 300 000 €	3 000- 30 000 €	< 3 000 €
5	Delay[1]	>12 mo	6-12 mo	3-6 mo	1-3 mo	1 mo<
6	Economical loss[1]					
	(1) Special example Where F= Fatality SI= Serious Injury MI= Minor Injury					

A descriptive classification of harms (consequence of occurrence) based on the types of harm faced to discriminate consequences into the categories is given in Table 5.8 for 3 folds (bands) of classification.

Table 5.8 Examples of harm categories (BS 8800:2004, pg.47)

Harm category [a] (examples)	Slight harm	Moderate harm	Extreme harm
Health	Nuisance and irritation (e.g. headaches); temporary ill health leading to discomfort (e.g. diarrhoea).	Partial hearing loss; dermatitis; asthma; work related upper limb disorders; ill health leading to permanent minor disability.	Acute fatal diseases; severe life shortening diseases; permanent substantial disability.
Safety	Superficial injuries; minor cuts and bruises; eye irritation from dust.	Lacerations; burns; concussion; serious sprains; minor fractures.	Fatal injuries; amputations; multiple injuries; major fractures.
[a] The health and safety harm categories are effectively defined by quoting examples and these lists are not exhaustive.			

5.6.2.3 Categories of risk on the basis of risk level

Risk categories are defined by establishing a risk matrix using categories for likelihood of harm and categories for severity of harm as its variables. In this matrix risks are classified as:

- Very high (quantitative value : 15,16, 20, 25)
- High (" " : 10,12)
- Medium (" " : 8, 9)
- Low (" " : 5, 6)
- Very low (" " : 1, 2, 3, 4)

In Figure 5.8, categories of risk on the base of risk level are shown on a risk matrix as combination of category for likelihood of harm and category for severity of harm (see next page).

Probability of Occurrence (P)		Severity of Consequence (S)				
		Disastrous	Severe	Serious	Considerable	Insignificant
		5	4	3	2	1
Very likely	5	25 Very high	20 Very high	15 Very high	10 High	5 Low
Likely	4	20 Very high	16 Very high	12 High	8 Medium	4 Very low
Occasional	3	15 Very high	12 High	9 Medium	6 Low	3 Very low
Unlikely	2	10 High	8 Medium	6 Low	4 Very low	2 Very low
Very unlikely	1	5 Low	4 Very low	3 Very low	2 Very low	1 Very low

Unacceptable

Unwanted

Acceptable

Negligible

Figure 5.8 Risk matrix and risk categories on the basis of risk level
(Özkılıç, Ö.: 2005, Chapter 4, Fig.35; BS 8800:2004, pg.49)

5.6.2.4 Risk classification on the basis of risk acceptance

The actions to be carried out for each hazard depend on whether the related risk is classified as:

- Unacceptable (quantitative value : 15, 16, 20, 25)
- Unwanted (" " : 5, 6, 8, 9, 10,12)
- Acceptable (" " : 3, 4)
- Negligible (" " : 1, 2)

So at the final stage all risks should be classified in the meaning of acceptability.

Figure 5.9 shows the risk matrix including category for likelihood of harm and category for severity of harm as variables and corresponding risk class on the basis of risk acceptance.

Probability of Occurrence (P)		Severity of Consequence (S)				
		Disastrous	Severe	Serious	Considerable	Insignificant
		5	4	3	2	1
Very likely	5	25 Unacceptable	20 Unacceptable	15 Unacceptable	10 Unwanted	5 Unwanted
Likely	4	20 Unacceptable	16 Unacceptable	12 Unwanted	8 Unwanted	4 Acceptable
Occasional	3	15 Unacceptable	12 Unwanted	9 Unwanted	6 Unwanted	3 Acceptable
Unlikely	2	10 Unwanted	8 Unwanted	6 Unwanted	4 Acceptable	2 Negligible
Very unlikely	1	5 Unwanted	4 Acceptable	3 Acceptable	2 Negligible	1 Negligible

Figure 5.9 Risk matrix on the basis of risk acceptance (Eskesen, S.D., Tengborg, P., Kampmann,J., Veicherts T.H. : 2004, ITA, pg.227)

5.6.2.5 Direct relation between risk categories based on risk level and risk acceptance

A simple risk categorization is also possible by direct relation between risk categories based on risk level and risk acceptance.

Table 5.9 shows a simple risk categorization related with risk acceptance.

Table 5.9 A simple risk categorization (BS 8800::2004, pg.49)

Category of risk	Evaluation of tolerability
Very low (Level 1, 2, 3, 4)	Acceptable (or Negligible)
Low (Level 5, 6)	Risks that should be reduced so that they are tolerable or acceptable (Unwanted)
Medium (Level 8, 9)	
High (Level 10, 12)	
Very high (Level 15, 16, 20, 25)	Unacceptable

5.7 Application for Üsküdar Station civil and structural works (Üsküdar Underground Station Construction Site)

In the subsequent part of the thesis, it is tried to present the application of hazard identification, risk assessment and determining controls aspects of occupational health and safety topic within the framework of an integrated OH&S management system for Üsküdar Underground Station construction. It is considered as a typical application for cut and cover underground station construction. The application is presented in tables and in the frame of how an hazard identification, risk assessment and determining controls processes should be carried out for an successful OH&S management system establishment as explained in the previous sections. In this respect, the steps of the whole process are discriminated into “activity analysis and hazard identification”, “event analysis in the scope of hazard identification”, “risk assessment before mitigation”, “mitigation measures”, “risk assessment after mitigation”, “Risk Register” procedures and documented through the Table 5.10.1 to Table 5.10.6 respectively.

Additionally, photographs in Figure 5.10 and Figure 5.11 show a general view and a construction stage from the Üsküdar Underground Station Construction Site.

Figure 5.10 A general view of the Üsküdar Station Construction Site

Figure 5.11 A stage from Üsküdar Station Construction

Table 5.10.1 Activity analysis and hazard identification for Üsküdar Station

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS					
Activity Analysis and Hazard Identification					
Work	Main Activity	Activity	Process (HAZARD)	Work Place	Equipment Plant
Supply	Material Supply		EQUIP	AREA	Truck
Supply	Concrete Supply		EQUIP	AREA	T.Mixer+Pump
Supply/waste	Unloading/Loading		EQUIP	AREA	Loader
Installations	Electrical Works		ELECT	AREA	
Installations	Mechanical Works		MECH	AREA	
Foundation Base Preparation	Ground levelling	Earthworks	EARTH	SHFT	
Foundation Base Preparation	Ground levelling	Earthworks	HAND	SHFT	
Foundation Base Preparation	Dewatering	Earthworks	TOOL	SHFT	Portable pump
Foundation Base Preparation	Dewatering	Earthworks	ELECT	SHFT	
Foundation Base Preparation	Lean Concrete	Concreting	TOOL	SHFT	
Foundation Base Preparation	Diaphragm Wall Surface Prep	Chipping	TOOL	SHFT	Pneumatic hammer
Foundation Base Preparation	Diaphragm Wall Surface Prep	Chipping	HEIGHT	SHFT	
Foundation Base Preparation	Diaphragm Wall Surface Prep	Chipping	COMP	SHFT	Compressor
Foundation Base Preparation	Diaphragm Wall Surface Prep	Shotcrete/ Plaster	TOOL	SHFT	

Table 5.10.1 Activity analysis and hazard identification for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS					
Activity List for OH&S RAMP					
Work	Main Activity	Activity	Process (HAZARD)	Work Place	Equipment Plant
Foundation Base Preparation	Waterproofing	Membrane installation	HAND	SHFT	
Foundation Base Preparation	Waterproofing	Membrane installation	HEIGHT	SHFT	
Base Level	Base Level	Formwork+ Reinforcement	HAND	SHFT	
Base Level	Base Level	Formwork+ Reinforcement	COLDWORK	SHFT	Benchwork
Base Level	Base Level	Formwork+ Reinforcement	HOTWORK	SHFT	Welding machine
Base Level	Base Level	Waterstop installation	HEIGHT	SHFT	
Base Level	Base Level	Waterstop installation	HAND	SHFT	
Base Level	Base Level	Temperature monitoring	HAND	SHFT	
Base Level	Base Level	Temperature monitoring	ELECT	SHFT	Monitoring device
Base Level	Base Level	Temperature monitoring	HEIGHT	SHFT	Monitoring device

Table 5.10.1 Activity analysis and hazard identification for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS					
Activity List for OH&S RAMP					
Work	Main Activity	Activity	Process (HAZARD)	Work Place	Equipment Plant
Base Level	Base Level	Cooling pipe installation	HAND	SHFT	
Base Level	Base Level	Cooling pipe installation	HEIGHT	SHFT	
Base Level	Base Level	Concreting	TOOL	SHFT	Vibrator
Base Level	Base Level	Curing, sheet installation	HAND	SHFT	
Base Level	Strut/Waling Beam Removal	Scaffolding	HAND	SHFT	
Base Level	Strut/Waling Beam Removal	Scaffolding	HEIGHT	SHFT	
Base Level	Strut/Waling Beam Removal	Scaffolding	HOTWORK	SHFT	Welding machine
Base Level	Strut/Waling Beam Removal	Cutting	TOOL	SHFT	
Base Level	Strut/Waling Beam Removal	Breaking	COMP	SHFT	Compressor
Base Level	Strut/Waling Beam Removal	Breaking	TOOL	SHFT	Pneumatic hammer
Base Level	Strut/Waling Beam Removal	Removal of waste	LIFT	SHFT	
Base Level	Strut/Waling Beam Removal	Elevate by Crane or Clamshell	EQUIP	AREA/ SHFT	Clamshell
Base Level	Strut/Waling Beam Removal	Loading to Dump Truck	EQUIP	AREA	Loader
Base Level	Strut/Waling Beam Removal	Loading to Dump Truck	EQUIP	AREA/ SHFT	Loader

Table 5.10.1 Activity analysis and hazard identification for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS					
Activity List for OH&S RAMP					
Work	Main Activity	Activity	Process (HAZARD)	Work Place	Equipment Plant
Base Level	Strut/Waling Beam Removal	Transport of Waste Material	TRANS	AREA	Truck
Base to the -17.00 Level Slab	Walkway platform	Formwork+ Reinforcement	HAND	SHFT	
Base to the -17.00 Level Slab	Walkway platform	Formwork+ Reinforcement	COLDWORK	SHFT	Benchwork
Base to the -17.00 Level Slab	Walkway platform	Formwork+ Reinforcement	HOTWORK	SHFT	Welding machine
Base to the -17.00 Level Slab	Walkway platform	Concreting	TOOL	SHFT	Vibrator
Base to the -17.00 Level Slab	Diaphragm Wall Surface Prep	Chipping	TOOL	SHFT	Pneumatic hammer
Base to the -17.00 Level Slab	Diaphragm Wall Surface Prep	Chipping	HEIGHT	SHFT	
Base to the -17.00 Level Slab	Diaphragm Wall Surface Prep	Chipping	COMP	SHFT	Compressor
Base to the -17.00 Level Slab	Diaphragm Wall Surface Prep	Shotcrete/Plaster	TOOL	SHFT	
Base to the -17.00 Level Slab	Waterproofing	Membrane installation	HAND	SHFT	
Base to the -17.00 Level Slab	Waterproofing	Membrane installation	HEIGHT	SHFT	
Base to the -17.00 Level Slab	Sidewall and columns	Formwork+ Reinforcement	HAND	SHFT	
Base to the -17.00 Level Slab	Sidewall and columns	Formwork+ Reinforcement	COLDWORK	SHFT	Benchwork
Base to the -17.00 Level Slab	Sidewall and columns	Formwork+ Reinforcement	HOTWORK	SHFT	Welding machine
Base to the -17.00 Level Slab	Sidewall and columns	Concreting	TOOL	SHFT	Vibrator
Base to the -17.00 Level Slab	Strut/Waling Beam Removal	Scaffolding	HOTWORK	SHFT	Welding machine
Base to the -17.00 Level Slab	Strut/Waling Beam Removal	Cutting	TOOL	SHFT	
Base to the -17.00 Level Slab	Strut/Waling Beam Removal	Breaking	COMP	SHFT	Compressor
Base to the -17.00 Level Slab	Strut/Waling Beam Removal	Breaking	TOOL	SHFT	Pneumatic hammer
Base to the -17.00 Level Slab	Strut/Waling Beam Removal	Removal of waste	LIFT	SHFT	

Table 5.10.1 Activity analysis and hazard identification for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS					
Activity List for OH&S RAMP					
Work	Main Activity	Activity	Process (HAZARD)	Work Place	Equipment Plant
Base to the -17.00 Level Slab	-17.00 level slab	Scaffolding	HAND	SHFT	
Base to the -17.00 Level Slab	-17.00 level slab	Formwork+ Reinforcement	HAND	SHFT	
Base to the -17.00 Level Slab	-17.00 level slab	Formwork+ Reinforcement	COLDWORK	SHFT	Benchwork
Base to the -17.00 Level Slab	-17.00 level slab	Formwork+ Reinforcement	HOTWORK	SHFT	Welding machine
Base to the -17.00 Level Slab	-17.00 level slab	Concreting	TOOL	SHFT	Vibrator
Base to the -17.00 Level Slab	Diaphragm Wall Surface Prep	Chipping	TOOL	SHFT	Pneumatic hammer
Base to the -17.00 Level Slab	Diaphragm Wall Surface Prep	Chipping	HEIGHT	SHFT	
Base to the -17.00 Level Slab	Diaphragm Wall Surface Prep	Chipping	COMP	SHFT	Compressor
Base to the -17.00 Level Slab	Diaphragm Wall Surface Prep	Shotcrete/Plaster	TOOL	SHFT	
Base to the -17.00 Level Slab	Waterproofing	Membrane installation	HAND	SHFT	
Base to the -17.00 Level Slab	Waterproofing	Membrane installation	HEIGHT	SHFT	
Base to the -17.00 Level Slab	Sidewall and columns	Formwork+ Reinforcement	HAND	SHFT	
Base to the -17.00 Level Slab	Sidewall and columns	Formwork+ Reinforcement	COLDWORK	SHFT	Benchwork
Base to the -17.00 Level Slab	Sidewall and columns	Formwork+ Reinforcement	HOTWORK	SHFT	Welding machine
Base to the -17.00 Level Slab	Sidewall and columns	Concreting	TOOL	SHFT	Vibrator
Between Slabs for other levels	Temporary strut installation	Installation	HOTWORK	SHFT	Welding machine

Table 5.10.1 Activity analysis and hazard identification for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS					
Activity List for OH&S RAMP					
Work	Main Activity	Activity	Process (HAZARD)	Work Place	Equipment Plant
Between Slabs for other levels	Temporary strut installation	Installation	LIFT	AREA/SHFT	Crane
Between Slabs for other levels	Strut/Waling Beam Removal	Scaffolding	HOTWORK	SHFT	Welding machine
Between Slabs for other levels	Strut/Waling Beam Removal	Cutting	TOOL	SHFT	
Between Slabs for other levels	Strut/Waling Beam Removal	Breaking	COMP	SHFT	Compressor
Between Slabs for other levels	Strut/Waling Beam Removal	Breaking	TOOL	SHFT	Pneumatic hammer
Between Slabs for other levels	Strut/Waling Beam Removal	Removal of waste	LIFT	SHFT	
Between Slabs for other levels	-11.00 level slab	Scaffolding	HAND	SHFT	
Between Slabs for other levels	-11.00 level slab	Formwork+ Reinforcement	HAND	SHFT	
Between Slabs for other levels	-11.00 level slab	Formwork+ Reinforcement	COLDWORK	SHFT	Benchwork
Between Slabs for other levels	-11.00 level slab	Formwork+ Reinforcement	HOTWORK	SHFT	Welding machine
Between Slabs for other levels	-11.00 level slab	Concreting	TOOL	SHFT	Vibrator
Backfill	Earthworks	Earthworks	EARTH	AREA/SHFT	

Table 5.10.2 Event analysis in the scope of hazard identification for Üsküdar Station

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS							
IDENTIFICATION OF HAZARD - EVENT ANALYSIS							
No	Process (HAZARD)	Root Causes				Hazards/ Top Events	Consequent Risks
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description
1.0	HEALTH						
1.1	All Employee	1.Lack of medical checks at recruitment 2.Lack of periodical medical checks 3.Unhygiene conditions 4.Insufficient medical applications	X	X	X	Mental and physical insufficiency of employee	1.Accidents 2.Increasing DAFW 3.Decreasing productivity
1.2	Tools-SPME (Noise Sources)	1.Excessive noise at site 2.Lack of noise control measures 3.Working very close to source 4.Inappropriate PPE 5.Working long durations at noisy site 6.Lack of awareness	X	X		Noise	1.Loss of hear 2.Psychological effect

Table 5.10.2 Event analysis in the scope of hazard identification for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS							
IDENTIFICATION OF HAZARD - EVENT ANALYSIS							
No	Process (HAZARD)	Root Causes				Hazards/ Top Events	Consequent Risks
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description
2.0	SAFETY						
2.1	Area/Shaft Security	1.Lack of security measures 2.Unauthorized entry/transpass 3.Unaccompanied visitors 4.Lack of awareness	X	X	X	Accidents Security incidents	Fatality
2.2	Own Employee/ Subcontractors	1.Lack of skill and competency 2.Lack of awareness 3.Lack of proper PPE	X	X	X	Accidents	Fatality
2.3	All Equipment/ Tools/material	1.Unsuitable equipment/tool/material 2.Substandard equipment/tool/material 3.Lack of maintenance and repair 4.Inappropriate operational conditions 5.Incorrect operation	X	X	X	Accidents	Fatality

Table 5.10.2 Event analysis in the scope of hazard identification for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS							
IDENTIFICATION OF HAZARD - EVENT ANALYSIS							
No	Process (HAZARD)	Root Causes				Hazards/ Top Events	Consequent Risks
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description
2.4	All Operations	1.Lack of operation control 2.Lack of process control	X	X	X	Accidents	Fatality
2.5	Special Operations with High Risk	1.Lack of Task Specific HSE Plan 2.Lack of permit to work	X	X	X	Accidents	Fatality
2.6	Emergency Situations	1.Lack of emergency response plan 2.Lack of rescue plan 3.Lack of skill/competency/ awareness 4.Lack of liaison with Authorities	X	X	X	Emergency situations	Fatality
2.7	Fire	1.Combustibles materials 2.Flammables 3.Ignition sources 4.Low control means	X	X	X	Fire at area/shaft	Fatality

Table 5.10.2 Event analysis in the scope of hazard identification for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS							
IDENTIFICATION OF HAZARD - EVENT ANALYSIS							
No	Process (HAZARD)	Root Causes				Hazards/ Top Events	Consequent Risks
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description
2.8	Flood	1.Surface runoff 2.Dyke level LT design flood WL 3.Failure of dyke 4.No early warning 5.Insufficient emergency response 6.No emergency rescue	X	X	X	Flooding of shaft	Fatality
2.9	Collapse	1.Lack skill/competency/ awareness 2.Equipment/material failure 3.Uncontrolled vehicle	X	X	X	Equipment/ material falling into shaft	Fatality
2.10	Accidents						
2.10.1	Equipment	1.Struck by other equipment 2.Mechanical failure 3.Unbalanced equipment 4.Uncertified operator 5.Lack of skill/competency/ awareness	X	X	X	1.Trapped 2.Struck/ Crashed 3.Knocked down	Fatality

Table 5.10.2 Event analysis in the scope of hazard identification for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS							
IDENTIFICATION OF HAZARD - EVENT ANALYSIS							
No	Process (HAZARD)	Root Causes				Hazards/ Top Events	Consequent Risks
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description
2.10.2	Earthworks	1.Struck by other equipment 2.Mechanical failure 3.Unbalanced equipment 4.Uncertified operator 5.Lack of skill/competency/ awareness	X	X	X	1.Trapped 2.Struck/ Crashed 3.Knocked down	Fatality
2.10.3	Electrical Works	1.Induction/arching from HV 2.Arching 3.Live power lines 3.Direct contact 4.Lack of skill/competency/ awareness	X	X	X	1.Electrical shock 2.Burn by arching	Fatality
2.10.4	Mechanical Works	1.Rupture of pipe/pump/plant 2.Failure/movement of parts 3.Lack of skill/competency/ awareness	X	X	X	1.Crashed 2.Knocked down	Serious Injury

Table 5.10.2 Event analysis in the scope of hazard identification for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS							
IDENTIFICATION OF HAZARD - EVENT ANALYSIS							
No	Process (HAZARD)	Root Causes				Hazards/ Top Events	Consequent Risks
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description
2.10.5	Lifting	1.Struck by other equipment 2.Mechanical failure 3.Unbalanced equipment 4.Lack of skill/competency/ awareness	X	X	X	1.Struck/ Crashed 2.Knocked down	Fatality
2.10.6	Working at height	1.Struck by other equipment 2.Failure of platform 3.Unsafe platform 4.Lack of risk control measures 5.Lack of skill/competency/ awareness	X	X	X	1.Fall down 2.Struck by falling object	Fatality
2.10.7	Hotwork	1.Breakdown of equipment 2.Misuse of equipment 3.Lack of skill/competency/ awareness 4.Lack of proper PPE	X	X		1.Burn	Serious Injury

Table 5.10.2 Event analysis in the scope of hazard identification for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS							
IDENTIFICATION OF HAZARD - EVENT ANALYSIS							
No	Process (HAZARD)	Root Causes				Hazards/ Top Events	Consequent Risks
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description
2.10.8	Coldwork	1.Breakdown of equipment 2.Misuse of equipment 3.Lack of skill/competency/ awareness	X	X		1.Struck/ Crushed 2.Knocked down	Serious Injury
2.10.9	Tools	1.Breakdown of equipment 2.Failure/rupture 3.Movement of parts 4.Misuse of equipment 5.Lack of skill/competency/ awareness	X	X		1.Crushed	Serious Injury
2.10.10	Compressed air	1.Breakdown of equipment 2.Failure/rupture 3.Movement of parts 4.Misuse of equipment 5.Lack of skill/competency/ awareness	X	X		1.Struck/ Crashed 2.Exposure to high pressure	Fatality
2.10.11	Manual handling	Lack of skill/competency/ awareness	X	X		1.Crushed	Serious Injury
2.11	Traffic Road Acc.						
2.11.1	Transport	1.Failure of vehicle 2.Failure to follow traffic rules 3.Lack of skill/competency/ awareness	X	X	X	1.Road traffic accidents	Fatality

Table 5.10.3 Risk assessment before mitigation for Üsküdar Station

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS							
Risk Assessment Before Mitigation							
No	Process (Hazard)	Before Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
1.0	HEALTH						
1.1	All Employee	Occasion	3	Consider	2	6	Unwant
1.2	Tools-SPME (Noise Sources)	Likely	4	Consider	2	8	Unwant
2.0	SAFETY						
2.1	Area/Shaft Security	Occasion	3	Serious	3	9	Unwant
2.2	Own Employee/ Subcontractors	Occasion	3	Serious	3	9	Unwant
2.3	All Equipment/ Tools/material	Occasion	3	Severe	4	12	Unwant
2.4	All Operations	Occasion	3	Severe	4	12	Unwant
2.5	Special Operations with High Risk	Occasion	3	Severe	4	12	Unwant
2.6	Emergency Situations	Occasion	3	Severe	4	12	Unwant
2.7	Flood	Occasion	3	Severe	4	12	Unwant
2.8	Fire	Occasion	3	Severe	4	12	Unwant
2.9	Collapse	Occasion	3	Disastrous	5	15	Unaccept
2.10	Accidents						
2.10.1	Equipment	Occasion	3	Severe	4	12	Unwant
2.10.2	Earthworks	Occasion	3	Severe	4	12	Unwant
2.10.3	Electrical Works	Occasion	3	Severe	4	12	Unwant
2.10.4	Mechanical Works	Occasion	3	Consider	2	6	Unwant
2.10.5	Lifting	Occasion	3	Severe	4	12	Unwant
2.10.6	Working at height	Occasion	3	Severe	4	12	Unwant
2.10.7	Hotwork	Occasion	3	Consider	2	6	Unwant
2.10.8	Coldwork	Occasion	3	Consider	2	6	Unwant
2.10.9	Tools	Occasion	3	Consider	2	6	Unwant
2.10.10	Compressed air	Occasion	3	Serious	3	9	Unwant
2.10.11	Manual handling	Occasion	3	Consider	2	6	Unwant
2.11	Traffic Road Acc.						
2.11.1	Transport	Occasion	3	Severe	4	12	Unwant

Table 5.10.4 Mitigation measures for Üsküdar Station

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS				
Mitigation Measures				
No	Process (Hazard)	Mitigation	Proposed Actions	In Charge
1.0	HEALTH			
1.1	All Employee	1.HS Plan 2.Medical, Welfare and Hygiene Procedure	1.Implement the Plan and Procedure 2.Medical checks at recruitment 3.Periodical medical checks 4.Hygiene inspections 5.Medical applications as required 6.Inspection 7.Awareness	1.Const. 2.QHSE
1.2	Tools-SPME (Noise Sources)	1.Noise and Vibration Control Procedure 2.CE Site Specific Plan for Noise Control at CST Sites	1.Implement the Plan and Procedure 2.PPE: Earplug, ear muff 3.Avoid noisy work 4.Control noise level 5.Exchange crew 6.Time break to crew 7.Noise doze measurement 8.Testing/maintenance of equipment 9.Awareness	1.Const. 2.QHSE
2.0	SAFETY			
2.1	Area/Shaft Security	1.Security Plan 2.Visitors Control Procedure for Work Site	1.Implement the Plan and Procedure 2.Additional measures if required 3.Heavy duty barrier and guardrail around shaft 4.Inspection 5.Induction to visitors 6.Accompanying visitors 7.Awareness	1.Const. 2.QHSE

Table 5.10.4 Mitigation measures for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS				
Mitigation Measures				
No	Process (Hazard)	Mitigation	Proposed Actions	In Charge
2.2	Own Employee/ Subcontractors	1.General HSE Rules Procedure 2.Subcontractor HSE Management Procedure 3.PPE Procedure	1.Implement the Procedures 2.Selection of employee/Subcontractor 3.HSE induction to all employee 4.System/technical/ emergency training 5.Skill and competency training 6.Awareness 7.Communication	1.Const. 2.QHSE
2.3	All Equipment/ Tools/material	Procurement Procedure Requirements as per 1.Law 2.Standards 3.Rules of art 4.Method Statement 5.Technical Specifications	1.Implement Procurement Procedure 2.Compliance with the requirements 3.Equipment/product certificates 4.Tests/inspection 5.Maintenance/repair options	1.Const. 2.QHSE
2.4	All Operations	1.Risk Subregisters 2.CIQP and HSE RAMP 3.Procedures	1.Implement the Operation and Process Control Measures 2.Review RAMP 3.Management/Supervion/ Monitoring 4.Skill/competency/ awareness 5.Communication	1.Const. 2.QHSE
2.5	Special Operations with High Risk	1.Task Specific HSE Plan 2.Permit to Work Procedure	1.Implement the Task Specific HSE Plan 2.Implement Permit to Work Procedure 3.Awareness	1.Const.

Table 5.10.4 Mitigation measures for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS				
Mitigation Measures				
No	Process (Hazard)	Mitigation	Proposed Actions	In Charge
2.6	Emergency Situations	Site Specific Emergency Response Plan	1.Implement the Plan 2.Review the Plan 2.Early warning 3.Skill/competency/awareness 4.Drill 5.Communication/Liaison with Authorities	1.Const.
2.7	Flood	Flood Risk Control Measures	1.Implement Risk Control Measures 2.Check/Maintenance of Risk Control Measures 3.Awareness	1.Const.
2.8	Fire	Fire Risk Control Measures	1.Implement Risk Control Measures 2.High control means 3.High security measures 4.Inspection of control means 5.Fire fighting equipment/maintenance 6.Awareness	1.Const.
2.9	Collapse	1.Lifting Operation Procedure 2.Construction Machines, Equipment and Machine Guard Procedure	1.Implement Procedures 2.Inspection of control measures 3.Test/inspection of equipment 4.Certified operator 5.Awareness	1.Const.

Table 5.10.4 Mitigation measures for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS				
Mitigation Measures				
No	Process (Hazard)	Mitigation	Proposed Actions	In Charge
2.10	Accidents			
2.10.1	Equipment	1.Construction Machines, Equipment and Machine Guard Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Certified operator 6.Awareness	1.Const.
2.10.2	Earthworks	1.Excavation Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Certified operator 6.Awareness	1.Const.
2.10.3	Electrical Works	1.Electrical Safety Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Certified electrician 6.Awareness	1.Const.
2.10.4	Mechanical Works	1.Instructions	1.Implement Instructions 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Certified mechanician 6.Awareness	1.Const.

Table 5.10.4 Mitigation measures for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS				
Mitigation Measures				
No	Process (Hazard)	Mitigation	Proposed Actions	In Charge
2.10.5	Lifting	1. Lifting Operation Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Certified operator and qualified crew 6.Awareness	1.Const.
2.10.6	Working at height	1.Working at Height and Scaffolding Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of scaffolding/eq. 4.Regular maintenance 5.Qualified worker 6.Awareness	1.Const.
2.10.7	Hotwork	1.Welding, Cutting and Grinding Procedure 2.PPE Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of welding equipment 4.Regular maintenance 5.Certified welder 6.Awareness	1.Const.
2.10.8	Coldwork	Instructions	1.Implement Instructions 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Skilled workers 6.Awareness	1.Const.

Table 5.10.4 Mitigation measures for Üsküdar Station - Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS				
Mitigation Measures				
No	Process (Hazard)	Mitigation	Proposed Actions	In Charge
2.10.9	Tools	Instructions	1.Implement Instructions 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Skilled workers 6.Awareness	1.Const.
2.10.10	Compressed air	1.Compressed Air Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Skilled workers 6.Awareness	1.Const.
2.10.11	Manual handling	Instructions	1.Implement Instructions 2.Supervision 3.Awareness	1.Const.
2.11	Traffic Road Acc.			
2.11.1	Transport	1. Specific HSE Plan	1.Implement Plan 2.Use approved routes 3.Use parking areas 4.Inspection 5.Test/inspection of equipment 6.Regular maintenance 7.Skilled workers 8.Awareness 9.Traffic insurance	1.Const.

Table 5.10.5 Risk assessment after mitigation for Üsküdar Station

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS							
Risk Assessment After Mitigation							
No	Process (Hazard)	After Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
1.0	HEALTH						
1.1	All Employee	Unlike	2	Consider	2	4	Accept
1.2	Tools-SPME (Noise Sources)	Unlike	2	Consider	2	4	Accept
2.0	SAFETY						
2.1	Area/Shaft Security	Unlike	2	Consider	2	4	Accept
2.2	Own Employee/ Subcontractors	Unlike	2	Consider	2	4	Accept
2.3	All Equipment/ Tools/material	Unlike	2	Consider	2	4	Accept
2.4	All Operations	Unlike	2	Consider	2	4	Accept
2.5	Special Operations with High Risk	V.Unlike	1	Severe	4	4	Accept
2.6	Emergency Situations	Unlike	2	Consider	2	4	Accept
2.7	Flood	V.Unlike	1	Severe	4	4	Accept
2.8	Fire	V.Unlike	1	Severe	4	4	Accept
2.9	Collapse	V.Unlike	1	Severe	4	4	Accept
2.10	Accidents						
2.10.1	Equipment	Unlike	2	Consider	2	4	Accept
2.10.2	Earthworks	Unlike	2	Consider	2	4	Accept
2.10.3	Electrical Works	Unlike	2	Consider	2	4	Accept
2.10.4	Mechanical Works	Unlike	2	Consider	2	4	Accept
2.10.5	Lifting	Unlike	2	Consider	2	4	Accept
2.10.6	Working at height	Unlike	2	Consider	2	4	Accept
2.10.7	Hotwork	Unlike	2	Consider	2	4	Accept
2.10.8	Coldwork	Unlike	2	Consider	2	4	Accept
2.10.9	Tools	Unlike	2	Consider	2	4	Accept
2.10.10	Compressed air	Unlike	2	Consider	2	4	Accept
2.10.11	Manual handling	Unlike	2	Consider	2	4	Accept
2.11	Traffic Road Acc.						
2.11.1	Transport	Unlike	2	Consider	2	4	Accept

Table 5.10.6 Risk Register for Üsküdar Station

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS																					
RISK REGISTER																					
No	Process (Hazard)	Root Causes				Hazards/ Top Events	Consequent Risks	Before Mitigation						Mitigation	Proposed Actions	After Mitigation						In Charg.
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	Frequency of Occurence		Consequence		Risk Class				Frequency of Occurrence		Consequence		Risk Class		
								Desc.	Freq.	Severity		Rat.	Acc.			Desc.	Freq.	Severity		Rat.	Acc.	
1.0	HEALTH																					
1.1	All Employee	1.Lack of medical checks at recruitment 2.Lack of periodical medical checks 3.Unhygiene conditions 4.Insufficient medical applications	X	X	X	Mental and physical insufficiency of employee	1.Accidents 2.Increasing DAFW 3.Decreasing productivity	Occ.	3	Consd.	2	6	Unw.	1.HS Plan 2.Medical, Welfare and Hygiene Procedure	1.Implement the Plan and Procedure 2.Medical checks at recruitment 3.Periodical medical checks 4.Hygiene inspections 5.Medical applications as required 6.Inspection 7.Awareness	Unlike	2	Consd.	2	4	Acc.	Const/ HSE
1.2	Tools-SPME (Noise Sources)	1.Excessive noise at site 2.Lack of noise control measures 3.Working very close to source 4.Inappropriate PPE 5.Working long durations at noisy site 6.Lack of awareness	X	X		Noise	1.Loss of hear 2.Psychological effect	Likely	4	Consd.	2	8	Unw.	1.Noise and Vibration Control Procedure 2.CE Site Specific Plan for Noise Control at CST Sites	1.Implement the Plan and Procedure 2.PPE: Earplug, ear muff 3.Avoid noisy work 4.Control noise level 5.Exchange crew 6.Time break to crew 7.Noise doze measurement 8.Testing/ maintenance of equipment 9.Awareness	Unlike	2	Consd.	2	4	Acc.	Const/ HSE

Table 5.10.6 Risk Register for Üsküdar Staion – Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS																					
RISK REGISTER																					
No	Process (Hazard)	Root Causes				Hazards/ Top Events	Consequent Risks	Before Mitigation						Mitigation	Proposed Actions	After Mitigation						In Charg.
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	Frequency of Occurence		Consequence		Risk Class				Frequency of Occurrence		Consequence		Risk Class		
								Desc.	Freq.	Severity		Rat.	Acc.			Desc.	Freq.	Severity		Rat.	Acc.	
2.0	SAFETY																					
2.1	Area / Shaft Security	1.Lack of security measures 2.Unauthorized entry/transpass 3.Unaccompanied visitors 4.Lack of awareness	X	X	X	Accidents Security incidents	Fatality	Occ.	3	Serious	3	9	Unw.	1.Security Plan 2.Visitors Control Procedure for Work Site	1.Implement the Plan and Procedure 2.Additional measures if required 3.Heavy duty barrier and guardrail around shaft 4.Inspection 5.Induction to visitors 6.Accompanying visitors 7.Awareness	Unlike	2	Consd.	2	4	Acc.	Const/ HSE
2.2	Own Employee/ Subcontractors	1.Lack of skill and competency 2.Lack of awareness 3.Lack of proper PPE	X	X	X	Accidents	Fatality	Occ.	3	Serious	3	9	Unw.	1.General HSE Rules Procedure 2.Subcontractor HSE Management Procedure 3.PPE Procedure	1.Implement the Procedures 2.Selection of employee/ Subcontractor 3.HSE induction to all employee 4.System/technical/ emergency training 5.Skill and competency training 6.Awareness 7.Communication	Unlike	2	Consd.	2	4	Acc.	Const/ HSE

Table 5.10.6 Risk Register for Üsküdar Staion – Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS																						
RISK REGISTER																						
No	Process (Hazard)	Root Causes				Hazards/ Top Events	Consequent Risks	Before Mitigation						Mitigation	Proposed Actions	After Mitigation						In Charg.
								Frequency of Occurence		Consequence		Risk Class				Frequency of Occurrence		Consequence		Risk Class		
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	Desc.	Freq.	Severity		Rat.	Acc.			Desc.	Freq.	Severity		Rat.	Acc.	
2.3	All Equipment/ Tools/ material	1.Unsuitable equipment/tool/ material 2.Substandard equipment/tool/ material 3.Lack of maintenance and repair 4.Inappropriate operational conditions 5.Incorrect operation	X	X	X	Accidents	Fatality	Occ.	3	Severe	4	12	Unw.	Procurement Procedure Requirements as per 1.Law 2.Standards 3.Rules of art 4.Method Statement 5.Technical Specifications	1.Implement Procurement Procedure 2.Compliance with the requirements 3.Equipment/product certificates 4.Tests/inspection 5.Maintenance/repair options	Unlike	2	Consd.	2	4	Acc.	Const/ HSE
2.4	All Operations	1.Lack of operation control 2.Lack of process control	X	X	X	Accidents	Fatality	Occ.	3	Severe	4	12	Unw.	1.Risk Subregisters 2.CIQP and HSE RAMP 3.Procedures	1.Implement the Operation and Process Control Measures 2.Review RAMP 3.Management/ Supervion/ Monitoring 4.Skill/competency/ awareness 5.Communication	Unlike	2	Consd.	2	4	Acc.	Const/ HSE
2.5	Special Operations with High Risk	1.Lack of Task Specific HSE Plan 2.Lack of permit to work	X	X	X	Accidents	Fatality	Occ.	3	Severe	4	12	Unw.	1.Task Specific HSE Plan 2.Permit to Work Procedure	1.Implement the Task Specific HSE Plan 2.Implement Permit to Work Procedure 3.Awareness	V.Unlike	1	Severe	4	4	Acc.	Const.

Table 5.10.6 Risk Register for Üsküdar Staion – Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS																						
RISK REGISTER																						
No	Process (Hazard)	Root Causes				Hazards/ Top Events	Consequent Risks	Before Mitigation						Mitigation	Proposed Actions	After Mitigation						In Charg.
								Frequency of Occurence		Consequence		Risk Class				Frequency of Occurrence		Consequence		Risk Class		
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	Desc.	Freq.	Severity		Rat.	Acc.			Desc.	Freq.	Severity		Rat.	Acc.	
2.6	Emergency Situations	1.Lack of emergency response plan 2.Lack of rescue plan 3.Lack of skill/competency/ awareness 4.Lack of liaison with Authorities	X	X	X	Emergency situations	Fatality	Occ.	3	Severe	4	12	Unw.	Site Specific Emergency Response Plan	1.Implement the Plan 2.Review the Plan 2.Early warning 3.Skill/competency /awareness 4.Drill 5.Communication/ Liaison with Authorities	Unlike	2	Consd.	2	4	Acc.	Const.
2.7	Flood	1.Surface runoff 2.Dyke level LT design flood WL 3.Failure of dyke 4.No early warning 5.Insufficient emergency response 6.No emergency rescue	X	X	X	Flooding of shaft	Fatality	Occ.	3	Severe	4	12	Unw.	Flood Risk Control Measures Risk Sub-Register	1.Implement Risk Control Measures 2.Check/ Maintenance of Risk Control Measures 3.Awareness	V.Unlike	1	Severe	4	4	Acc.	Const.
2.8	Fire	1.Combustibles materials 2.Flammables 3.Ignition sources 4.Low control means	X	X	X	Fire at area/shaft	Fatality	Occ.	3	Severe	4	12	Unw.	Fire Risk Control Measures Risk Sub-Register	1.Implement Risk Control Measures 2.High control means 3.High security measures 4.Inspection of control means 5.Fire fighting equipment/ maintenance 6.Awareness	V.Unlike	1	Severe	4	4	Acc.	Const.

Table 5.10.6 Risk Register for Üsküdar Staion – Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS																						
RISK REGISTER																						
No	Process (Hazard)	Root Causes				Hazards/ Top Events	Consequent Risks	Before Mitigation						Mitigation	Proposed Actions	After Mitigation						In Charg.
								Frequency of Occurence		Consequence		Risk Class				Frequency of Occurrence		Consequence		Risk Class		
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	Desc.	Freq.	Severity		Rat.	Acc.			Desc.	Freq.	Severity		Rat.	Acc.	
2.9	Collapse	1.Lack skill/competency/ awareness 2.Equipment/ material failure 3.Uncontrolled vehicle	X	X	X	Equipment/ material falling into shaft	Fatality	Occ.	3	Disast.	5	15	Unw.	1.Lifting Operation Procedure 2.Construction Machines, Equipment and Machine Guard Procedure	1.Implement Procedures 2.Inspection of control measures 3.Test/inspection of equipment 4.Certified operator 5.Awareness	V.Unlik e	1	Severe	4	4	Acc.	Const.
2.10	Accidents																					
2.10.1	Equipment	1.Struck by other equipment 2.Mechanical failure 3.Unbalanced equipment 4.Uncertified operator 5.Lack of skill/competency/ awareness	X	X	X	1.Trapped 2.Struck/ Crashed 3.Knocked down	Fatality	Occ.	3	Severe	4	12	Unw.	1.Construction Machines, Equipment and Machine Guard Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Certified operator 6.Awareness	Unlike	2	Consd.	2	4	Acc.	Const.
2.10.2	Earthworks	1.Struck by other equipment 2.Mechanical failure 3.Unbalanced equipment 4.Uncertified operator 5.Lack of skill/competency/ awareness	X	X	X	1.Trapped 2.Struck/ Crashed 3.Knocked down	Fatality	Occ.	3	Severe	4	12	Unw.	1.Excavation Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Certified operator 6.Awareness	Unlike	2	Consd.	2	4	Acc.	Const.

Table 5.10.6 Risk Register for Üsküdar Staion – Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS																					
RISK REGISTER																					
No	Process (Hazard)	Root Causes				Hazards/ Top Events	Consequent Risks	Before Mitigation						Mitigation	Proposed Actions	After Mitigation						In Charg.
								Frequency of Occurence		Consequence		Risk Class				Frequency of Occurrence		Consequence		Risk Class		
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	Desc.	Freq.	Severity		Rat.	Acc.			Desc.	Freq.	Severity		Rat.	Acc.	
2.10.3	Electrical Works	1.Induction/arching from HV 2.Arching 3.Live power lines 3.Direct contact 4.Lack of skill/competency /awareness	X	X	X	1.Electrical shock 2.Burn by arching	Fatality	Occ.	3	Severe	4	12	Unw.	1.Electrical Safety Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Certified electrician 6.Awareness	Unlike	2	Consd.	2	4	Acc.	Const.
2.10.4	Mechanical Works	1.Rupture of pipe/pump/plant 2.Failure/movement of parts 3.Lack of skill/competency/ awareness	X	X	X	1.Crashed 2.Knocked down	Serious Injury	Occ.	3	Consd.	2	6	Unw.	1.Instructions	1.Implement Instructions 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Certified mechanician 6.Awareness	Unlike	2	Consd.	2	4	Acc.	Const.
2.10.5	Lifting	1.Struck by other equipment 2.Mechanical failure 3.Unbalanced equipment 4.Lack of skill/competency/ awareness	X	X	X	1.Struck/ Crashed 2.Knocked down	Fatality	Occ.	3	Severe	4	12	Unw.	1. Lifting Operation Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Certified operator and qualified crew 6.Awareness	Unlike	2	Consd.	2	4	Acc.	Const.

Table 5.10.6 Risk Register for Üsküdar Staion – Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS																							
RISK REGISTER																							
No	Process (Hazard)	Root Causes				Hazards/ Top Events	Consequent Risks	Before Mitigation						Mitigation	Proposed Actions	After Mitigation						In Charg.
								Frequency of Occurence		Consequence		Risk Class				Frequency of Occurrence		Consequence		Risk Class		
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	Desc.	Freq.	Severity		Rat.	Acc.			Desc.	Freq.	Severity		Rat.	Acc.	
2.10.6	Working at height	1.Struck by other equipment 2.Failure of platform 3.Unsafe platform 4.Lack of risk control measures 5.Lack of skill/competency/ awareness	X	X	X	1.Fall down 2.Struck by falling object	Fatality	Occ.	3	Severe	4	12	Unw.	1.Working at Height and Scaffolding Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of scaffolding/eq. 4.Regular maintenance 5.Qualified worker 6.Awareness	Unlike	2	Consd.	2	4	Acc.	Const.
2.10.7	Hotwork	1.Breakdown of equipment 2.Misuse of equipment 3.Lack of skill/competency/ awareness 4.Lack of proper PPE	X	X		1.Burn	Serious Injury	Occ.	3	Consd.	2	6	Unw.	1.Welding, Cutting and Grinding Procedure 2.PPE Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of welding eq. 4.Regular maintenance 5.Certified welder 6.Awareness	Unlike	2	Consd.	2	4	Acc.	Const.
2.10.8	Coldwork	1.Breakdown of equipment 2.Misuse of equipment 3.Lack of skill/competency/ awareness	X	X		1.Struck/ Crushed 2.Knocked down	Serious Injury	Occ.	3	Consd.	2	6	Unw.	Instructions	1.Implement Instructions 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Skilled workers 6.Awareness	Unlike	2	Consd.	2	4	Acc.	Const.

Table 5.10.6 Risk Register for Üsküdar Staion – Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS																							
RISK REGISTER																							
No	Process (Hazard)	Root Causes				Hazards/ Top Events	Consequent Risks	Before Mitigation						Mitigation	Proposed Actions	After Mitigation						In Charg.
								Frequency of Occurence		Consequence		Risk Class				Frequency of Occurrence		Consequence		Risk Class		
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	Desc.	Freq.	Severity		Rat.	Acc.			Desc.	Freq.	Severity		Rat.	Acc.	
2.10.9	Tools	1.Breakdown of equipment 2.Failure/rupture 3.Movement of parts 4.Misuse of equipment 5.Lack of skill/competency/ awareness	X	X		1.Crushed	Serious Injury	Occ.	3	Consd.	2	6	Unw.	Instructions	1.Implement Instructions 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Skilled workers 6.Awareness	Unlike	2	Consd.	2	4	Acc.	Const.
2.10.10	Compressed air	1.Breakdown of equipment 2.Failure/rupture 3.Movement of parts 4.Misuse of equipment 5.Lack of skill/competency/ awareness	X	X		1.Struck/ Crashed 2.Exposure to high pressure	Fatality	Occ.	3	Serious	3	9	Unw.	1.Compressed Air Procedure	1.Implement Procedure 2.Supervision 3.Test/inspection of equipment 4.Regular maintenance 5.Skilled workers 6.Awareness	Unlike	2	Consd.	2	4	Acc.	Const.
2.10.11	Manual handling	Lack of skill/competency/ awareness	X	X		1.Crushed	Serious Injury	Occ.	3	Consd.	2	6	Unw.	Instructions	1.Implement Instructions 2.Supervision 3.Awareness	Unlike	2	Consd.	2	4	Acc.	Const.

Table 5.10.6 Risk Register for Üsküdar Staion – Continued

ÜSKÜDAR STATION CIVIL AND STRUCTURAL WORKS																						
RISK REGISTER																						
No	Process (Hazard)	Root Causes				Hazards/ Top Events	Consequent Risks	Before Mitigation						Mitigation	Proposed Actions	After Mitigation						In Charg.
								Frequency of Occurence		Consequence		Risk Class				Frequency of Occurrence		Consequence		Risk Class		
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	Desc.	Freq.	Severity		Rat.	Acc.			Desc.	Freq.	Severity		Rat.	Acc.	
2.11	Traffic Road Acc.																					
2.11.1	Transport	1.Failure of vehicle 2.Failure to follow traffic rules 3.Lack of skill/competency/ awareness	X	X	X	1.Road traffic accidents	Fatality	Occ.	3	Severe	4	12	Unw.	1. Specific HSE Plan	1.Implement Plan 2.Use approved routes 3.Use parking areas 4.Inspection 5.Test/inspection of equipment 6.Regular maintenance 7.Skilled workers 8.Awareness 9.Traffic insurance	Unlike	2	Consd.	2	4	Acc.	Const.

5.8 Application for EPM type TBM tunnel construction (Yedikule Tunnel Construction Site)

In the following part of the thesis, it is tried to present the application of hazard identification, risk assessment and determining controls aspects of occupational health and safety topic within the framework of an integrated OH&S management system for EPM type TBM tunnel construction (Yedikule Tunnel Construction Site). The application is presented in tables and in the frame of how an hazard identification, risk assessment and determining controls processes should be carried out for an successful OH&S management system establishment as explained in the previous sections. In this respect, the steps of the whole process are discriminated into “activity & event analysis and hazard identification”, “risk assessment before mitigation”, “mitigation measures”, “risk assessment after mitigation”, “Risk Register” procedures. Each procedures are applied for sources of hazards which are “accidents in tunneling”, “accidents”, “fire”, “flood”, “earthquake”, “alignment conflicts”, “tunneling incidents”, “maintenance”, “tunnel installations”, “structural hazards at shaft”. “Activity & event analysis and hazard identification” procedure is documented for each source of hazard through the Table 5.11.1 to Table 5.11.10; “risk assessment before mitigation” procedure through the Table 5.11.11 to Table 5.11.20; “mitigation measures” procedure through the Table 5.11.21 to Table 5.11.30; “risk assessment after mitigation” procedure through the Table 5.11.31 to Table 5.11.40 and “Risk Register” procedure through the Table 5.11.41 to Table 5.11.50 in the same manner.

Photographs in Figure 5.12 and Figure 5.13 show two different construction stages from the EPM type TBM tunnel construction.

Figure 5.12 A stage from EPB TBM Tunnel Construction

Figure 5.13 A stage from EPB TBM Tunnel Construction

Table 5.11.1 Activity & event analysis and hazard identification for EPB TBM tunnels - accidents in tunneling

EPB TBM TUNNEL WORKS										
Item No	Process (Hazard)	Root Causes				Hazards/Top Events	Consequent Risks			
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Desc.	H	S	E
ACC	CONSTRUCTION-ACCIDENTS IN TUNNELLING									
01	Confined Space	1.Too narrow space 2.Lack of escape 3.Lack of skill/competency	X	X		1.Trapped 2.Suffocation	F		X	
02	TBM	1.Rock fall 2.Fall down 3.Uncertified operator	X	X	X	1.Crushed 2.Trapped	F		X	
03	Belt Conveyor	1.Loose rock 2.Unguarded machinery 3.Uncertified operator 4.Lack of awareness	X	X	X	1.Crushed 2.Trapped	F		X	
04	Segment Erection	1.Uncertified operator 2.Mechanical breakdown 3.Lack of awareness	X	X	X	1.Crushed 2.Knocked down	F		X	
05	Tunnel Transport	1.Uncertified operator 2.Damaged tracks 3.Deformation of rolling stock 4.Overspeeding 5.De-railing of rolling stock	X	X	X	1.Crushed 2.Trapped	F		X	
06	" "	1.Uncertified operator 2.Misuse of locomotive 3.Overspeeding	X	X	X	1.Crushed 2.Trapped 3.Run into	F		X	

Table 5.11.1 Activity & event analysis and hazard identification for EPB TBM tunnels - accidents in tunneling - Continued

EPB TBM TUNNEL WORKS										
Item No	Process (Hazard)	Root Causes				Hazards/Top Events	Consequent Risks			
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Desc.	H	S	E
ACC	CONSTRUCTION-ACCIDENTS IN TUNNELLING									
07	Toxic Gases	1.Diffusion of gases from ground 2.Spreading of gases 3.Lack of detection/alarm 4.Lack of awareness 5.Lack of emergency response	X	X	X	1.Irritation 2.Burn 3.Injury 4.Fatality	F		X	
08	Explosive Gases	1.Diffusion of gases from ground 2.Spreading of gases 3.Lack of detection/alarm 4.Lack of awareness 5.Lack of emergency response	X	X	X	1.Explosion 2.Fire 3.Fatality	F		X	
09	Chemicals	1.Spill of chemicals 2.Spreading of chemicals 3.Contact with chemicals 4.Lack of awareness	X	X	X	1.Irritation 2.Burn 3.Injury	SI		X	

Table 5.11.2 Activity & event analysis and hazard identification for EPB TBM tunnels - accidents

EPB TBM TUNNEL WORKS										
Item No	Process (Hazard)	Root Causes				Hazards/Top Events	Consequent Risks			
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Desc.	H	S	E
ACC	CONSTRUCTION-ACCIDENTS									
01	Running Trains	1.Running trains 2.Unrestricted access 3.No signal	X	X	X	1.Struck/ Crashed 2.Knocked down	F		X	
02	Overhead HV Power Lines	1.Induction 2.Arching 3.Lack of skill/competency	X	X	X	1.Electrical shock 2.Burn by arching	F		X	
03	False Currents	1.Live power lines 2.False currents into ground	X	X	X	1.Electrical shock 2.Burn by arching	F		X	
04	Electrical Works	1.Induction/arching from HV 2.Arching 3.Live power lines 3.Direct contact 4.Lack of skill/competency	X	X	X	1.Electrical shock 2.Burn by arching	F		X	
05	Equipments	1.Moving equipment 2.Mechanical failure 3.Uncertified operator 4.Lack of awareness	X	X	X	1.Trapped 2.Struck/ Crashed 3.Knocked down	F		X	
06	Heavy Lifting	1.Struck by other equipment 2.Mechanical failure 3.Unbalanced equipment 4.Lack of skill/competency	X	X	X	1.Struck/ Crashed 2.Knocked down	F		X	

Table 5.11.2 Activity & event analysis and hazard identification for EPB TBM tunnels - accidents - Continued

EPB TBM TUNNEL WORKS										
Item No	Process (Hazard)	Root Causes				Hazards/Top Events	Consequent Risks			
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Desc.	H	S	E
ACC	CONSTRUCTION-ACCIDENTS									
07	Work at Height	1.Struck by other equipment 2.Failure of platform 3.Unsafe platform 4.Lack of skill/competency	X	X	X	1.Fall down 2.Struck by falling object	F		X	
08	Earthworks	1.Struck by other equipment 2.Mechanical failure 3.Unbalanced equipment 4Lack of skill/competency	X	X	X	1.Trapped 2.Struck/ Crashed 3.Knocked down	F		X	
09	Supervision/ Inspect./ Survey	1.Moving equipment 2.Lack of awareness	X		X	1.Trapped 2.Struck/ Crashed 3.Knocked down 4.Trip	F		X	
10	Cold Work	1.Breakdown of equipment 2.Misuse of equipment 3.Lack of awareness	X	X		1.Struck/ Crushed 2.Knocked down	F		X	
11	Hot Work	1.Breakdown of equipment 2.Misuse of equipment 3.Lack of awareness	X	X		1.Burn	SI		X	

Table 5.11.2 Activity & event analysis and hazard identification for EPB TBM tunnels - accidents - Continued

EPB TBM TUNNEL WORKS										
Item No	Process (Hazard)	Root Causes				Hazards/Top Events	Consequent Risks			
		Initiating Events	Hum.	Mat./ Eq.	Ext.		Desc.	H	S	E
ACC	CONSTRUCTION-ACCIDENTS									
12	Hand Tools	1.Breakdown of equipment 2.Misuse of equipment 3.Lack of awareness	X	X		1.Crushed	SI		X	
13	Manual Handling	1.Lack of awareness	X	X		1.Crushed	SI		X	
14	Pipe/Pump/ Stationery Plant	1.Rupture of pipe/pump/plant 2.Lack of awareness	X	X		1.Crashed 2.Knocked down	SI		X	
15	Compressed Air	1.Breakdown of equipment 2.Rupture of pipe 3.Misuse of equipment 4.Lack of awareness	X	X		1.Exposure to high pressure	SI		X	

Table 5.11.3 Activity & event analysis and hazard identification for EPB TBM tunnels - fire

EPB TBM TUNNEL WORKS									
Item No	Root Causes				Hazards/Top Events	Consequent Risks			
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E
FIRE	CONSTRUCTION-FIRE								
01	1.Combustibles : Normal 2.Flammables : Low 3.Ignition sources: Normal 4.Control means : Normal	X	X	X	1.Fire in tunnel	1.Fatality 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X
02	1.Combustibles : Normal 2.Flammables : Low 3.Ignition sources: Normal 4.Control means : Normal	X	X	X	1.Fire at shaft	1.Fatality 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X
03	1.Combustibles : Normal 2.Flammables : Low 3.Ignition sources: Normal 4.Control means : Normal	X	X	X	1.Fire at area	1.Fatality 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X
04	1.Spreading of fire outside	X	X	X	1.Fire at Community/ Built Environment	1.Fatality 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X

Table 5.11.4 Activity & event analysis and hazard identification for EPB TBM tunnels - flood

EPB TBM TUNNEL WORKS									
Item No	Root Causes				Hazards/Top Events	Consequent Risks			
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E
FLD	CONSTRUCTION-FLOOD								
01	1.Surface runoff LE design 2.Dyke level LT design flood WL 3.Failure of dyke 4.No early warning 5.Insufficient emergency plan 6.No emergency rescue	X	X	X	1.Flooding of shaft and tunnel	1.Inundation of tunnel 2.Short circuit 3.Fatality 4.Damage to env. 5.Damage to eq. 6.Interruption of work 7.Loss of time 8.Economic Loss		X	X
02	1.Surface runoff GT design 2.No early warning 3.Insufficient emergency plan 4.No emergency rescue	X	X	X	1.Flooding of shaft and tunnel	1.Inundation of tunnel 2.Short circuit 3.Fatality 4.Damage to env. 5.Damage to eq. 6.Interruption of work 7.Loss of time 8.Economic Loss		X	X

Table 5.11.5 Activity & event analysis and hazard identification for EPB TBM tunnels - earthquake

EPB TBM TUNNEL WORKS									
Item No	Root Causes				Hazards/Top Events	Consequent Risks			
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E
EQ	CONSTRUCTION-EARTHQUAKE								
01	1.Earthquake LE Design 2.Lack of EQ resistance 3.Design mistake	X	X	X	1.Catastrophic failure by EQ	1.Damage to tunnel lining 2.Collapse of tunnel 3.Damage to BE 4.Fatality 5.Interruption of work 6.Loss of time 7.Economic Loss		X	X
02	1.Earthquake GT Design			X	1.Catastrophic failure by EQ	1.Damage to tunnel lining 2.Collapse of tunnel 3.Damage to BE 4.Fatality 5.Interruption of work 6.Loss of time 7.Economic Loss		X	X

Table 5.11.6 Activity & event analysis and hazard identification for EPB TBM tunnels - alignment conflicts

EPB TBM TUNNEL WORKS									
Item No	Root Causes				Hazards/Top Events	Consequent Risks			
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E
ALIGN	CONSTRUCTION-ALIGNMENT CONFLICTS								
01	1.Movement of base point 2.Mis-survey 3.Alignment conflicts	X	X	X	1.Deviation from alignment	1.Interruption of work 2.Corrective work 3.Loss of time 4.Economic Loss			
02	1.Boulders 2.Tree trunk 3.Hindrance in front of tunnel face 4.Blocking of cutter head 5.Breakdown of TBM 6.Interruption of tunnelling	X	X	X	1.Instability of tunnel	1.Injury 2.Damage to BE 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X
03	1.Unknown/unidentified well/borehole/cavity 2.Void not completely backfilled 3.TBM operation with compressed air	X	X	X	1.Very high settlements 2.Blow out 3.Tunnel face instability	1.Injury 2.Damage to BE 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X
04	1.Lack of condition survey 2.Unknown/unidentified deep foundations 3.Breakdown of TBM 4.Interruption of tunnelling	X	X	X	1.Damage to deep foundations	1.Injury 2.Damage to BE 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X
05	1.Backfilled harbour	X	X	X	1.Problems during tunnelling (3+400-3+700)	1.Damage to BE 2.Interruption of work 3.Loss of time 4.Economic Loss		X	X

Table 5.11.7 Activity & event analysis and hazard identification for EPB TBM tunnels - tunnelling incidents

EPB TBM TUNNEL WORKS									
Item No	Root Causes				Hazards/Top Events	Consequent Risks			
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E
TUN	CONSTRUCTION-TUNNELLING INCIDENTS								
01	1.Sand lenses or sandy layers with low or no cohesion with narrow grain size distribution at top of tunnel excavation 2.Non cohesive loose soils 3.Mixed face conditions 4.Significant strength difference btw materials at excavation face 5.Overcutting 6.Hindrance at tunnel face 7.Insufficient face pressure 8.Lack of competence 9.Breakdown of equipment	X	X	X	1.Face instability 2.High surface settlements	1.Injury 2.Damage to BE 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X
02	1.Non-cohesive soils with high permeability 2.TBM in semi-closed mode or maintenance mode 3.Compressed air is used 4.Too high face pressure 5.Lack of competence 6.Breakdown of equipment	X	X	X	1.Heave of ground 2.Uplift 3.Blow out	1.Injury 2.Damage to BE 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X
03	1.Cohesive soil with high swelling index	X	X	X	1.Ground swelling (expected as very low)	1.Damage to BE		X	X
04	1.Insufficient side wall between tunnels 2.Excessive ground deformations	X	X	X	1.Side wall collapse of twin tunnels	1.Interruption of tunnelling 2.Fatality		X	X

Table 5.11.7 Activity & event analysis and hazard identification for EPB TBM tunnels - tunnelling incidents - Continued

EPB TBM TUNNEL WORKS									
Item No	Root Causes				Hazards/Top Events	Consequent Risks			
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E
TUN	CONSTRUCTION-TUNNELLING INCIDENTS								
05	1.Excessive surcharge load on tunnel 2.Poor geological conditions 3.Face completely in soft ground 4.Under critical structures 5.Stoppage of tunnelling for long periods 6.Insufficient segment strength	X	X	X	1.Failure of segment lining 2.Collapse of tunnel	1.Injury 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X
06	1.Excessive surcharge load on tunnel 2.Poor geological conditions 3.Face completely in soft ground 4.Under critical structures 5.Stoppage of tunnelling for long periods 6.Insufficient segment strength	X	X	X	1.Collapse of tunnel	1.Injury 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X
07	1.Cohesionless ground at tunnel face 2.Sand or coarse grained soils 3.Consistency of soil is not plastic to semi-liquid 4.No proper soil pulp to seal tunnel face 5.Permeability of soil too high to set up a proper face pressure	X	X	X	1.Uncontrolled water inflow into the cutter head chamber (1+950-2+650)	1.Interruption of tunnelling		X	X
08	1.Uncontrolled water inflow 2.Delays with backfill grouting 3.Retardation of setting time of backfill grout	X	X	X	1.Segment floating	1.Interruption of tunnelling		X	X

Table 5.11.8 Activity & event analysis and hazard identification for EPB TBM tunnels - maintenance

EPB TBM TUNNEL WORKS									
Item No	Root Causes				Hazards/Top Events	Consequent Risks			
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E
INC	CONSTRUCTION-MAINTENANCE								
	Change of cutting tools								
01	1.Difficult ground conditions 2.Less durable cutting tools 3.Inappropriate operation of TBM 4.Insufficient maintenance 5.High abrasion of cutting tools	X	X	X	1.Frequent change of cutting tools	1.Interruption of work 2.Loss of time 3.Economic loss		X	
02	1.Entry into cutting head chamber 2.Change of cutting tools	X	X	X	1.Trapped in confined space	1.Injury 2.Interruption of work 3.Loss of time 4.Economic loss		X	
03	1.Entry into cutting head chamber 2.Changing from backside is not possible 3.Entry into front space 4.Change of cutting tools	X	X	X	1.Trapped in confined space 2.Trapped under collapse 3.Suffocation	1.Fatality 2.Interruption of work 3.Loss of time 4.Economic loss		X	
04	1.Entry into cutting head chamber 2.Changing from backside is not possible 3.Entry into front space 4.Sensitive structures above tunnel 5.High face pressure 6.Change of cutting tools under pressure 7.Sudden decompression	X	X	X	1.Trapped in confined space 2.Suffocation 3.Decompression sickness	1.Fatality 2.Interruption of work 3.Loss of time 4.Economic loss		X	

Table 5.11.9 Activity & event analysis and hazard identification for EPB TBM tunnels - tunnel installations

EPB TBM TUNNEL WORKS									
Item No	Root Causes				Hazards/Top Events	Consequent Risks			
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E
INS	CONSTRUCTION-TUNNEL INSTALLATIONS								
01	1.Unsuitable installation 2.Damage 3.Lack of maintenance 4.Lack of repair	X	X	X	1.Electrical installation out of order	1.Power cut off 2.Accident 3.Interruption of work 4.Loss of time 5.Economic Loss		X	
02	1.Unsuitable system 2.Damage 3.Lack of maintenance 4.Lack of repair	X	X	X	1.Lighting system out of order	1.Insufficient illumination 2.Accident 3.Interruption of work 4.Loss of time 5.Economic Loss		X	
03	1.Unsuitable equipment 2.Damage to eq. 3.Lack of repair 4.Lack of maintenance	X	X	X	1.Water supply system out of order	1.Water supply off 2.Interruption of work 3.Instability 4.Loss of time 5.Economic Loss		X	
04	1.Unsuitable system 2.Insufficient capacity 3.Power cut off 4.Damage to eq. 5.Lack of repair 6.Lack of maintenance	X	X	X	1.Ventilation system out of order	1.Insufficient ventilation 2.Interruption of work 3.Loss of time 4.Economic Loss		X	
05	1.Unsuitable system 2.Damage 3.Lack of maintenance 4.Lack of repair	X	X	X	1.Communication system out of order	1.Lack of communication 2.Lack of emergency response 3.Injury 4.Interruption of work		X	
06	1.Lack of care/awareness 2.Damage	X	X	X	1.Fire fighting installations missing	1.Lack of emergency response 2.Injury		X	
07	1.Lack of care/awareness 2.Damage	X	X	X	1.First aid installations missing	1.Lack of emergency response 2.Injury		X	

Table 5.11.10 Activity & event analysis and hazard identification for EPB TBM tunnels - structural hazards at shaft

EPB TBM TUNNEL WORKS									
Item No	Root Causes				Hazards/Top Events	Consequent Risks			
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E
STR	CONSTRUCTION-STRUCTURAL HAZARDS AT SHAFT								
01	1.Quick sand/boiling/piping 2.Heave of bottom of excavation	X	X	X	1.Failure at the foundation of shaft	1.Damage to env. 2.Interruption of work 3.Loss of time 4.Economic Loss		X	X
02	1.Insufficient support at foundation	X	X	X	1.Failure at foundation of side wall	1.Damage to env. 2.Interruption of work 3.Loss of time 4.Economic Loss		X	X
03	1.Insufficient material quality	X	X	X	1.Failure of piles	1.Damage to env. 2.Interruption of work 3.Loss of time 4.Economic Loss		X	X
04	1.Insufficient material quality	X	X	X	1.Failure of support system (Prestressed anchors)	1.Damage to env. 2.Interruption of work 3.Loss of time 4.Economic Loss		X	X
05	1.Excessive surcharge 2.Instability of side walls 3.Insufficient support system	X	X	X	1.Collapse of shaft	1.Injury 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X

Table 5.11.11 Risk assessment before mitigation for EPB TBM tunnels - accidents in tunneling

EPB TBM TUNNEL WORKS								
Item No	Process (Hazard)	Before Mitigation						
		Frequency of Occurrence		Consequence			Risk Class	
		Desc.	Freq.	Class	Severity		Rating	Accept
ACC	CONSTRUCTION-ACCIDENTS IN TUNNELLING							
01	Confined Space	Occasion	3	S	Serious	3	9	Unwant
02	TBM	Occasion	3	S	Serious	3	9	Unwant
03	Belt Conveyor	Occasion	3	S	Serious	3	9	Unwant
04	Segment Erection	Occasion	3	S	Serious	3	9	Unwant
05	Tunnel Transport	Occasion	3	S	Serious	3	9	Unwant
06	" "	Occasion	3	S	Serious	3	9	Unwant
07	Toxic Gases	Unlikely	2	S	Severe	4	8	Unwant
08	Explosive Gases	Unlikely	2	S	Severe	4	8	Unwant
09	Chemicals	Occasion	3	S	Consider	2	6	Unwant

Table 5.11.12 Risk assessment before mitigation for EPB TBM tunnels - accidents

EPB TBM TUNNEL WORKS								
Item No	Process (Hazard)	Before Mitigation						
		Frequency of Occurrence		Consequence			Risk Class	
		Desc.	Freq.	Class	Severity		Rating	Accept
ACC	CONSTRUCTION-ACCIDENTS							
01	Running Trains	Occasion	3	S	Serious	3	9	Unwant
02	Overhead HV Power Lines	Occasion	3	S	Serious	3	9	Unwant
03	False Currents	Occasion	3	S	Serious	3	9	Unwant
04	Electrical Works	Occasion	3	S	Severe	4	12	Unwant
05	Equipments	Occasion	3	S	Severe	4	12	Unwant
06	Heavy Lifting	Occasion	3	S	Severe	4	12	Unwant
07	Work at Height	Occasion	3	S	Severe	4	12	Unwant
08	Earthworks	Occasion	3	S	Severe	4	12	Unwant
09	Supervision/Inspect./ Survey	Occasion	3	S	Serious	3	9	Unwant

Table 5.11.12 Risk assessment before mitigation for EPB TBM tunnels - accidents - Continued

EPB TBM TUNNEL WORKS								
Item No	Process (Hazard)	Before Mitigation						
		Frequency of Occurrence		Consequence			Risk Class	
		Desc.	Freq	Class	Severity		Rating	Accept
ACC	CONSTRUCTION-ACCIDENTS							
10	Cold Work	Occasion	3	S	Serious	3	9	Unwant
11	Hot Work	Occasion	3	S	Consider	2	6	Unwant
12	Hand Tools	Occasion	3	S	Consider	2	6	Unwant
13	Manual Handling	Occasion	3	S	Consider	2	6	Unwant
14	Pipe/Pump/Stationery Plant	Occasion	3	S	Consider	2	6	Unwant
15	Compressed Air	Occasion	3	S	Consider	2	6	Unwant

Table 5.11.13 Risk assessment before mitigation for EPB TBM tunnels - fire

EPB TBM TUNNEL WORKS								
Item No	Hazards/Top Events	Before Mitigation						
		Frequency of Occurrence		Consequence			Risk Class	
		Desc.	Freq.	Class	Severity		Rating	Accept
FIRE	CONSTRUCTION-FIRE							
01	1.Fire in tunnel	Occasion	3	S	Severe	4	12	Unwant
02	1.Fire at shaft	Occasion	3	S	Severe	4	12	Unwant
03	1.Fire at area	Occasion	3	S	Severe	4	12	Unwant
04	1.Fire at Community/ Built Environment	Occasion	3	S	Severe	4	12	Unwant

Table 5.11.14 Risk assessment before mitigation for EPB TBM tunnels - flood

EPB TBM TUNNEL WORKS								
Item No	Hazards/Top Events	Before Mitigation						
		Frequency of Occurrence		Consequence			Risk Class	
		Desc.	Freq.	Class	Severity		Rating	Accept
FLD	CONSTRUCTION-FLOOD							
01	1.Flooding of shaft and tunnel	Occasion	3	S	Severe	4	12	Unwant
02	1.Flooding of shaft and tunnel	Unlike	2	S	Disaster	5	10	Unwant

Table 5.11.15 Risk assessment before mitigation for EPB TBM tunnels-earthquake

EPB TBM TUNNEL WORKS								
Item No	Hazards/Top Events	Before Mitigation						
		Frequency of Occurrence		Consequence			Risk Class	
		Desc.	Freq.	Class	Severity		Rating	Accept
EQ	CONSTRUCTION-EARTHQUAKE							
01	1.Catastrophic failure by EQ	Unlikely	2	C	Disaster	5	10	Unwant
02	1.Catastrophic failure by EQ	V.Unlike	1	C	Disaster	5	5	Unwant

Table 5.11.16 Risk assessment before mitigation for EPB TBM tunnels - alignment conflicts

EPB TBM TUNNEL WORKS								
Item No	Hazards/Top Events	Before Mitigation						
		Frequency of Occurrence		Consequence		Risk Class		
		Desc.	Freq.	Class	Severity		Rating	Accept
ALIGN	CONSTRUCTION-ALIGNMENT CONFLICTS							
01	1.Deviation from alignment	Occasion	3	T	Serious	3	9	Unwant
02	1. Instability of tunnel	Occasion	3	T	Serious	3	9	Unwant
03	1.Very high settlements 2.Blow out 3.Tunnel face instability	Occasion	3	T	Serious	3	9	Unwant
04	1.Damage to deep foundations	Occasion	3	T	Serious	3	9	Unwant
05	1.Problems during tunnelling (3+400-3+700)	Occasion	3	T	Serious	3	9	Unwant

Table 5.11.17 Risk assessment before mitigation for EPB TBM tunnels - tunnelling incidents

EPB TBM TUNNEL WORKS								
Item No	Hazards/Top Events	Before Mitigation						
		Frequency of Occurrence		Consequence			Risk Class	
		Desc.	Freq.	Class	Severity		Rating	Accept
TUN	CONSTRUCTION-TUNNELLING INCIDENTS							
01	1.Face instability 2.High surface settlements	Occasion	3	T	Serious	3	9	Unwant
02	1.Heave of ground 2.Uplift 3.Blow out	Occasion	3	T	Serious	3	9	Unwant
03	1.Ground swelling (expected as very low)	Occasion	3	T	Serious	3	9	Unwant
04	1.Side wall collapse of twin tunnels	Occasion	3	T	Serious	3	9	Unwant
05	1.Failure of segment lining 2.Collapse of tunnel	Occasion	3	T	Serious	3	9	Unwant
06	1.Collapse of tunnel	Occasion	3	T	Serious	3	9	Unwant
07	1.Uncontrolled water inflow into the cutter head chamber (1+950-2+650)	Occasion	3	T	Serious	3	9	Unwant
08	1.Segment floating	Occasion	3	T	Serious	3	9	Unwant

Table 5.11.18 Risk assessment before mitigation for EPB TBM tunnels - maintenance

EPB TBM TUNNEL WORKS								
Item No	Hazards/Top Events	Before Mitigation						
		Frequency of Occurrence		Consequence		Risk Class		
		Desc.	Freq.	Class	Severity		Rating	Accept
INC	CONSTRUCTION-MAINTENANCE							
01	1.Frequent change of cutting tools	Likely	4	T	Consider	2	8	Unwant
02	1.Trapped in confined space	Likely	4	S	Consider	2	8	Unwant
03	1.Trapped in confined space 2.Trapped under collapse 3.Suffocation	Unlikely	2	S	Serious	3	6	Unwant
04	1.Trapped in confined space 2.Suffocation 3.Decompression sickness	Unlikely	2	S	Serious	3	6	Unaccept

Table 5.11.19 Risk assessment before mitigation for EPB TBM tunnels - tunnel installations

EPB TBM TUNNEL WORKS								
Item No	Hazards/Top Events	Before Mitigation						
		Frequency of Occurrence		Consequence			Risk Class	
		Desc.	Freq.	Class	Severity		Rating	Accept
INS	CONSTRUCTION-TUNNEL INSTALLATIONS							
01	1.Electrical installation out of order	Occasion	3	S	Serious	3	9	Unwant
02	1.Lighting system out of order	Occasion	3	S	Serious	3	9	Unwant
03	1.Water supply system out of order	Occasion	3	S	Serious	3	9	Unwant
04	1.Ventilation system out of order	Occasion	3	S	Serious	3	9	Unwant
05	1.Communication system out of order	Occasion	3	S	Serious	3	9	Unwant
06	1.Fire fighting installations missing	Occasion	3	S	Serious	3	9	Unwant
07	1.First aid installations missing	Occasion	3	S	Serious	3	9	Unwant

Table 5.11.20 Risk assessment before mitigation for EPB TBM tunnels - structural hazards at shaft

EPB TBM TUNNEL WORKS								
Item No	Hazards/Top Events	Before Mitigation						
		Frequency of Occurrence		Consequence		Risk Class		
		Desc.	Freq.	Class	Severity		Rating	Accept
STR	CONSTRUCTION-STRUCTURAL HAZARDS AT SHAFT							
01	1.Failure at the foundation of shaft	Unlikely	2	C	Severe	4	8	Unwant
02	1.Failure at foundation of side wall	Unlikely	2	C	Severe	4	8	Unwant
03	1.Failure of piles	Unlikely	2	C	Severe	4	8	Unwant
04	1.Failure of support system (Prestressed anchors)	Unlikely	2	C	Severe	4	8	Unwant
05	1.Collapse of shaft	Unlikely	2	C	Severe	4	8	Unwant

Table 5.11.21 Mitigation measures for EPB TBM tunnels - accidents in tunneling

EPB TBM TUNNEL WORKS				
Item No	Process (Hazard)	Mitigation	Proposed Actions	In Charge
ACC	CONSTRUCTION-ACCIDENTS IN TUNNELLING			
01	Confined Space	1.Procedure	1.Certified workers 2.Training 3.Permit to work	1.Const.
02	TBM	1.Operation as per manual 2.PPE 3.Access ladder	1.Certified operator	1.Const.
03	Belt Conveyor	1.Cover to dangereous machine parts 2.Emergency off switch	1.Test/inspection 2.Certified operator 3.Training	1.Const.
04	Segment Erection	1.Certified operator 2.No entry into danger zone 3.Continuous collaboration 4.Proper PPE	1.Training to operator/crew 2.Instructions 3.Tool box 4.Visual contact with operator	1.Const.
05	Tunnel Transport	1.Certified operator 2.Maintenance/repair tracks 3.Maintenance/repair rolling stock 4.Speed limit 5.Speed alarm	1.Training to operator 2.Maintenance crew 3.Keep safe speed as max 10 km/h	1.Const.
06	" "	1.Certified operator 2.Speed limit 3.Speed alarm 4.Warning light at work area in tunnel	1.Training to operator 2.Instructions to operator 3.Tool box to tunnel workers 4.No work on rail track 5.Keep safe speed as max 10 km/h	1.Const.

Table 5.11.21 Mitigation measures for EPB TBM tunnels - accidents in tunneling - Continued

EPB TBM TUNNEL WORKS				
Item No	Process (Hazard)	Mitigation	Proposed Actions	In Charge
ACC	CONSTRUCTION-ACCIDENTS IN TUNNELLING			
07	Toxic Gases	1.Survey for gases 2.Detection of gases 3.Alarm levels for critical concentrations 4.Sufficient ventilation as per BS6164 5.Emergency response 6.Special PPE/masks 7.First aid/oxygen bottle 8.Medical care	1.TBM gas detection system 2.Additional gas detection system 3.Periodical maintenance 4.Periodical test on equipment 5.Emergency response plan 6.Training/drills	1.Const.
08	Explosive Gases	1.Survey for gases 2.Detection of gases 3.Alarm levels for critical concentrations 4.Sufficient ventilation as per BS6164 5.Emergency response 6.Special PPE/masks 7.First aid/oxygen bottle 8.Fire fighting	1.TBM gas detection system 2.Additional gas detection system 3.Periodical maintenance 4.Periodical test on equipment 5.Emergency response plan 6.Training/drills 7.Liaison with Authorities	1.Const.
09	Chemicals	1.Detection of gases 2.Alarm levels for critical concentrations 3.Sufficient ventilation as per BS6164 4.Emergency response 5.Special PPE/masks 6.MSDS/First aid 7.Medical care	1.TBM gas detection system 2.Additional gas detection system 3.Periodical maintenance 4.Periodical test on equipment 5.Emergency response plan 6.Training/drills	1.Const.

Table 5.11.22 Mitigation measures for EPB TBM tunnels - accidents

EPB TBM TUNNEL WORKS				
Item No	Process (Hazard)	Mitigation	Proposed Actions	In Charge
ACC	CONSTRUCTION-ACCIDENTS			
01	Running Trains	1.Perimeter fence 2.Controlled crossing 3.Safety signs	1.Induction 2.Special training	1.Const.
02	Overhead HV Power Lines	1.Implement TS HSE Plan	1.Induction 2.Special training 3.Permit to work	1.Const.
03	False Currents	1.Survey of cables 2.Cancel cables 3.Remove cables 4.Training	1.Induction 2.Special training 3.Permit to work	1.Const.
04	Electrical Works	1.Procedure	1.Test/inspection certificate by authority 2.Certified electrician 3.Training 4.Permit to work	1.Const.
05	Equipments	1.Procedure	1.Test/inspection certificate by authority 2.Certified operator 3.Training 4.Permit to work	1.Const.
06	Heavy Lifting	1.Procedure	1.Test/inspection certificate by authority 2.Certified operator 3.Training 4.Permit to work	1.Const.
07	Work at Height	1.Procedure	1.Test/inspection certificate by authority 2.Certified workers 3.Training 4.Permit to work	1.Const.

Table 5.11.22 Mitigation measures for EPB TBM tunnels - accidents - Continued

EPB TBM TUNNEL WORKS				
Item No	Process (Hazard)	Mitigation	Proposed Actions	In Charge
ACC	CONSTRUCTION-ACCIDENTS			
08	Earthworks	1.Procedure	1.Test/inspection certificate by authority 2.Certified operators 3.Training 4.Permit to work	1.Const.
09	Supervision/Inspect./ Survey	1.Instructions	1.Training	1.Const.
10	Cold Work	1.Procedure	1.Qualified workers 2.Training	1.Const.
11	Hot Work	1.Procedure	1.Qualified workers 2.Training	1.Const.
12	Hand Tools	1.Procedure	1.Qualified workers 2.Training	1.Const.
13	Manual Handling	1.Instructions	1.Training	1.Const.
14	Pipe/Pump/Stationery Plant	1.Instructions	1.Training	1.Const.
15	Compressed Air	1.Procedure	1.Qualified workers 2.Training	1.Const.

Table 5.11.23 Mitigation measures for EPB TBM tunnels - fire

EPB TBM TUNNEL WORKS				
Item No	Hazards/Top Events	Mitigation	Proposed Actions	In Charge
FIRE	CONSTRUCTION-FIRE			
01	1.Fire in tunnel	1.Control means: High 2.Security 3.Fire fighting 4.Liaison with fire brigade 5.Emergency plan	1.Inspection of control means 2.Fire fighting drills 3.Emergency evacuation drills 4.Training/awereness 5.Insurance	1.Const.
02	1.Fire at shaft	1.Control means: High 2.Security 3.Fire fighting 4.Liaison with fire brigade 5.Emergency plan	1.Inspection of control means 2.Fire fighting drills 3.Emergency evacuation drills 4.Training/awereness 5.Insurance	1.Const.
03	1.Fire at area	1.Control means: High 2.Security 3.Fire fighting 4.Liaison with fire brigade 5.Emergency plan	1.Inspection of control means 2.Fire fighting drills 3.Emergency evacuation drills 4.Training/awereness 5.Insurance	1.Const.
04	1.Fire at Community/ Built Environment	1.Control means: High 2.Security 3.Fire fighting 4.Liaison with fire brigade 5.Emergency plan	1.Inspection of control means 2.Fire fighting drills 3.Emergency evacuation drills 4.Training/awereness 5.Insurance	1.Const.

Table 5.11.24 Mitigation measures for EPB TBM tunnels -flood

EPB TBM TUNNEL WORKS				
Item No	Hazards/Top Events	Mitigation	Proposed Actions	In Charge
FLD	CONSTRUCTION-FLOOD			
01	1.Flooding of shaft and tunnel	1.Hydrological study to estimate flood Q 2.Hydraulic study to estimate flood WL 3.Dyke level with adequate free board 4.Sound dyke 5.Early warning 6.Emergency evacuation plan 7.Emergency rescue plan	1.Review studies 2.Repair/maintenance dyke 3.Follow weather forecasts 4.Watching for early warning 5.Emergency evacuation drills 6.Emergency rescue drills 7.Training/awereness 8.Insurance	1.DSG 2.Const.
02	1.Flooding of shaft and tunnel	1.Hydrological study to estimate flood Q 2.Hydraulic study to estimate flood WL 3.Dyke level with adequate free board 4.Sound dyke 5.Early warning 6.Emergency evacuation plan 7.Emergency rescue plan	1.Follow weather forecasts 2.Watching for early warning 3.Emergency evacuation drills 4.Emergency rescue drills 5.Training/awereness 6.Insurance	1.DSG 2.Const.

Table 5.11.25 Mitigation measures for EPB TBM tunnels - earthquake

EPB TBM TUNNEL WORKS				
Item No	Hazards/Top Events	Mitigation	Proposed Actions	In Charge
EQ	CONSTRUCTION-EARTHQUAKE			
01	1.Catastrophic failure by EQ	1.Seismic design in accordance with req. 2.Tunnel construction facility as per BS 6164 3.Insurance cover	1.Design check/verification 2.Emergency Response Plan 3.Emergency evacuation drill 4.Liaison with Authorities	1.PM
02	1.Catastrophic failure by EQ	1.Tunnel construction facility as per BS 6164 2.Insurance cover	1.Design check/verification 2.Emergency Response Plan 3.Emergency evacuation drill 4.Liaison with Authorities	EMP

Table 5.11.26 Mitigation measures for EPB TBM tunnels - alignment conflicts

EPB TBM TUNNEL WORKS				
Item No	Hazards/Top Events	Mitigation	Proposed Actions	In Charge
ALIGN	CONSTRUCTION-ALIGNMENT CONFLICTS			
01	1.Deviation from alignment	1.Protection of base points 2.Cross check of survey system 3.Periodical calibration of equipment 4.High precision survey 5.More frequent survey	1.Regular checks of survey results 2.Monitoring of tunnel deformations	1.Const.
02	1.Instability of tunnel	1.Sufficient cutting tools 2.TBM to break minor boulders within cutting head 3.Sensitive control of face pressure 4.Conditioning of soil pulp if necessary 5.Treatment in case of very unfavourable ground conditions	1.TBM O&M Manual 2.Stop TBM, if boulders cannot be crushed by disc cutter 3.Stabilization of face 4.Apply air pressure 5.Empty cutting head chamber 6.Seal face if air consumption too high 7.Enter into chamber 8.Boulder to be removed	1.Const.
03	1.Very high settlements 2.Blow out 3.Tunnel face instability	1.Survey of wells 2.Geophysical investigation 3.Backfill and closure of wells, boreholes, cavity 4.New boreholes to be kept in safe distance	1.Stabilisation of tunnel face 2.Immediate backfill of well or borehole 3.Grouting at tunnel face if suitable	1.Const.
04	1.Damage to deep foundations	1.Condition survey 2.Identify deep foundations 3.Stabilisation of tunnel face	1.Stabilisation/ adaptation of foundation if possible 2.Removal of redundant foundation at tunnel face	1.Const.
05	1.Problems during tunnelling (3+400-3+700)	1.Condition survey 2.Identify possible problems 3.Stabilisation of tunnel face	1.Detailed study	1.Const.

Table 5.11.27 Mitigation measures for EPB TBM tunnels - tunnelling incidents

EPB TBM TUNNEL WORKS				
Item No	Hazards/Top Events	Mitigation	Proposed Actions	In Charge
TUN	CONSTRUCTION-TUNNELLING INCIDENTS			
01	1.Face instability 2.High surface settlements	1.Sensitive control of face pressure 2.Conditioning of soil pulp if necessary 3.Treatment in case of very unfavourable ground conditions 4.Monitoring 5.Application of trigger levels	1.TBM O&M Manual 2.Measures for settlement reduction 3.Increase of face pressure 4.Relation btw cutter head rotation and velocity of stroke 5.Condition of soil within cutter head chamber 6.Ground treatment	1.Const.
02	1.Heave of ground 2.Uplift 3.Blow out	1.Avoid semi-open mode within non-cohesive soil 2.Select allowable face pressure 3.Maintain face pressure below that 4.Avoid compressed air in areas where the foundation of buildings major utilities or wells are in a distance of less the 4 m	1.Decrease of face pressure	1.Const.
03	1.Ground swelling (expected as very low)	1.Controllable overcutter	1.TBM O&M Manual 2.Measures for settlement reduction	1.Const.
04	1.Side wall collapse of twin tunnels	1.Adequate cover and overburden 2.Treatment in case of very unfavourable ground conditions 3.Backfill grouting parallel to excavation 4.Monitoring 5.Application of trigger levels	1.TBM O&M Manual 2.Measures for settlement reduction 3.Monitoring tunnel deformations	1.Const.

Table 5.11.27 Mitigation measures for EPB TBM tunnels - tunnelling incidents - Continued

EPB TBM TUNNEL WORKS				
Item No	Hazards/Top Events	Mitigation	Proposed Actions	In Charge
TUN	CONSTRUCTION-TUNNELLING INCIDENTS			
05	1.Failure of segment lining 2.Collapse of tunnel	1.Adequate cover and overburden 2.Treatment in case of very unfavourable ground conditions 3.Backfill grouting parallel to excavation 4.Continuous tunnelling 5.Proper segment quality 6.Monitoring	1.Measures for settlement reduction 2.Monitoring tunnel deformations 3.w/o compressed air for quick maintenance	1.Const.
06	1.Collapse of tunnel	1.TBM damage to be repaired from outside	1.Stoppage of tunnelling 2.Access shaft	1.Const.
07	1.Uncontrolled water inflow into the cutter head chamber (1+950-2+650)	1.Conditioning of soil with foam,polymers or bentonite	1.Stop TBM 2.Close screw conveyor 3.Adopt conditioning of soil 4.Restart TBM 5.Slush pump at end of screw conveyor	1.Const.
08	1.Segment floating	1.Control of infow water 2.Backfill grouting parallel to excavation 3.Grout mix in conformity with requirements	1.Monitoring deviations	1.Const.

Table 5.11.28 Mitigation measures for EPB TBM tunnels - maitenance

EPB TBM TUNNEL WORKS				
Item No	Hazards/Top Events	Mitigation	Proposed Actions	In Charge
INC	CONSTRUCTION-MAINTENANCE			
01	1.Frequent change of cutting tools	1.Long durable cutting tools 2.Adjustment of torque and thrust to reduce wearing 3.Regular maintenance 4.Easy replacement type cutting tools	1.TBM O&M Manual	1.Const.
02	1.Trapped in confined space	1.Change of cutting tools from backside of cutter head 2.Permit to work	1.TBM O&M Manual 2.Change during maintenance shift	1.Const.
03	1.Trapped in confined space 2.Trapped under collapse 3.Suffocation	1.Change under less risky soil conditions 2.Semi-closed mode if possible 3.Scaffolding 4.Permit to work	1.TBM O&M Manual 2.Proper and regular maintenance of cutting tools 3.Safe locations for stoppafe of TBM to be defined in advance	1.Const.
04	1.Trapped in confined space 2.Suffocation 3.Decompression sickness	1.Change under less risky soil conditions 2.Treatment of ground 3.Semi-closed mode if possible 4.Scaffolding 5.PPE for work under pressure 6.Gradual pressure change 7.Compressed air equipment 8.Permit to work	1.TBM O&M Manual 2.Proper and regular maintenance of cutting tools 3.Safe locations for stoppafe of TBM to be defined in advance	1.Const.

Table 5.11.29 Mitigation measures for EPB TBM tunnels - tunnel installations

EPB TBM TUNNEL WORKS				
Item No	Hazards/Top Events	Mitigation	Proposed Actions	In Charge
INS	CONSTRUCTION-TUNNEL INSTALLATIONS			
01	1.Electrical installation out of order	1.Suitable installation 2.Periodical maintenance 3.Quick repairs 4.Spare parts	1.Periodical check/test 2.Report defects	1.Const.
02	1.Lighting system out of order	1.Suitable system 2.Special lighting at critical locations 3.Flashing warning lights at dangereous locations 4.Emergency lights 5.Waterproof installations 6.Periodical maintenance 7.Quick repairs	1.Periodical check of eq. 2.Battery lights in tunnel 3.Diesel set in operation	1.Const.
03	1.Water supply system out of order	1.Suitable installation 2.Periodical maintenance 3.Quick repairs 4.Spare parts	1.Water storage tanks	1.Const.
04	1.Ventilation system out of order	1.Suitable system 2.Diesel set 3.Automatic switch to diesel 4.Spare parts 5.Quick repair of damage 6.Periodical maintenance	1.Air ducts close to face 2.Seal joints properly 3.Adequate support to ducts 4.Periodical check of eq. 5.Evacuation of tunnel	1.Const.
05	1.Communication system out of order	1.Effective communication means 2.Supplementary system 3.Periodical maintenance 4.Quick repairs 5.Spare parts	1.Periodical check/test 2.Report defects 3.Fix emergency rescue plan 4.Emergency drills	1.Const.
06	1.Fire fighting installations missing	1.Fire extinguishers 2.Masks	1.Periodical check 2.Report defects	1.Const.
07	1.First aid installations missing	1.First aid kits	1.Periodical check 2.Report defects	1.Const.

Table 5.11.30 Mitigation measures for EPB TBM tunnels-structural hazards at shaft

EPB TBM TUNNEL WORKS				
Item No	Hazards/Top Events	Mitigation	Proposed Actions	In Charge
STR	CONSTRUCTION-STRUCTURAL HAZARDS AT SHAFT			
01	1.Failure at the foundation of shaft	1.Deep piles 2.Piles into impervious layer 3.Adequate FS against piping	1.Monitoring 2.Inspection/evaluation	1.Const. 2.DSG
02	1.Failure at foundation of side wall	1.Piles anchored into ground	1.Monitoring 2.Inspection/evaluation	1.Const. 2.DSG
03	1.Failure of piles	1.RC with C40 2.High workability 3.Suitable tremie concrete 4.QC on fresh concrete	1.Monitoring 2.Inspection/evaluation	1.Const. 2.QA/QC
04	1.Failure of support system (Prestressed anchors)	1.Prestressed anchoring 2.Adequate FS	1.Monitoring 2.Inspection/evaluation	1.Const. 2.QA/QC
05	1.Collapse of shaft	1.Compatible design with geotechnical requirements 2.Robust/sound design 3.Limit to surcharge load on slopes 4.Adequate FS including EQ	1.Design and development check/review 2.Special design study 3.Independent Design Verification (IDV) 4.Critical surcharge load	1.Const. 2.DSG

Table 5.11.31 Risk assessment after mitigation for EPB TBM tunnels - accidents in tunneling

EPB TBM TUNNEL WORKS							
Item No	Process (Hazard)	After Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
ACC	CONSTRUCTION-ACCIDENTS IN TUNNELLING						
01	Confined Space	V.Unlike	1	Serious	3	3	Accept
02	TBM	V.Unlike	1	Serious	3	3	Accept
03	Belt Conveyor	V.Unlike	1	Serious	3	3	Accept
04	Segment Erection	V.Unlike	1	Serious	3	3	Accept
05	Tunnel Transport	V.Unlike	1	Serious	3	3	Accept
06	" "	V.Unlike	1	Serious	3	3	Accept
07	Toxic Gases	Unlikely	2	Consider	2	4	Accept
08	Explosive Gases	Unlikely	2	Consider	2	4	Accept
09	Chemicals	Unlikely	2	Consider	2	4	Accept

Table 5.11.32 Risk assessment after mitigation for EPB TBM tunnels - accidents

EPB TBM TUNNEL WORKS							
Item No	Process (Hazard)	After Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
ACC	CONSTRUCTION-ACCIDENTS						
01	Running Trains	Unlikely	2	Consider	2	4	Accept
02	Overhead HV Power Lines	V.Unlike	1	Serious	3	3	Accept
03	False Currents	V.Unlike	1	Serious	3	3	Accept
04	Electrical Works	V.Unlike	1	Severe	4	4	Accept
05	Equipments	V.Unlike	1	Severe	4	4	Accept
06	Heavy Lifting	V.Unlike	1	Severe	4	4	Accept
07	Work at Height	V.Unlike	1	Severe	4	4	Accept

Table 5.11.32 Risk assessment after mitigation for EPB TBM tunnels - accidents - Continued

EPB TBM TUNNEL WORKS							
Item No	Process (Hazard)	After Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
ACC	CONSTRUCTION-ACCIDENTS						
08	Earthworks	V.Unlike	1	Severe	4	4	Accept
09	Supervision/Inspect./ Survey	V.Unlike	1	Serious	3	3	Accept
10	Cold Work	V.Unlike	1	Serious	3	3	Accept
11	Hot Work	Unlikely	2	Consider	2	4	Accept
12	Hand Tools	Unlikely	2	Consider	2	4	Accept
13	Manual Handling	Unlikely	2	Consider	2	4	Accept
14	Pipe/Pump/Stationery Plant	Unlikely	2	Consider	2	4	Accept
15	Compressed Air	Unlikely	2	Consider	2	4	Accept

Table 5.11.33 Risk assessment after mitigation for EPB TBM tunnels - fire

EPB TBM TUNNEL WORKS							
Item No	Hazards/Top Events	After Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
FIRE	CONSTRUCTION-FIRE						
01	1.Fire in tunnel	V.Unlike	1	Severe	4	4	Accept
02	1.Fire at shaft	V.Unlike	1	Severe	4	4	Accept
03	1.Fire at area	V.Unlike	1	Severe	4	4	Accept
04	1.Fire at Community/ Built Environment	V.Unlike	1	Severe	4	4	Accept

Table 5.11.34 Risk assessment after mitigation for EPB TBM tunnels - flood

EPB TBM TUNNEL WORKS							
Item No	Hazards/Top Events	After Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
FLD	CONSTRUCTION-FLOOD						
01	1.Flooding of shaft and tunnel	V.Unlike	1	Severe	4	4	Accept
02	1.Flooding of shaft and tunnel	V.Unlike	1	Severe	4	4	Accept

Table 5.11.35 Risk assessment after mitigation for EPB TBM tunnels - earthquake

EPB TBM TUNNEL WORKS							
Item No	Hazards/Top Events	After Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
EQ	CONSTRUCTION-EARTHQUAKE						
01	1.Catastrophic failure by EQ	V. Unlike	1	Severe	4	4	Accept
02	1.Catastrophic failure by EQ	V. Unlike	1	Severe	4	4	Accept

Table 5.11.36 Risk assessment after mitigation for EPB TBM tunnels - alignment conflicts

EPB TBM TUNNEL WORKS							
Item No	Hazards/Top Events	After Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
ALIGN	CONSTRUCTION-ALIGNMENT CONFLICTS						
01	1.Deviation from alignment	Unlike	2	Consider	2	4	Accept
02	1.Instability of tunnel	Unlike	2	Consider	2	4	Accept
03	1.Very high settlements 2.Blow out 3.Tunnel face instability	Unlike	2	Consider	2	4	Accept
04	1.Damage to deep foundations	Unlike	2	Consider	2	4	Accept
05	1.Problems during tunnelling (3+400-3+700)	Unlike	2	Consider	2	4	Accept

Table 5.11.37 Risk assessment after mitigation for EPB TBM tunnels - tunnelling incidents

EPB TBM TUNNEL WORKS							
Item No	Hazards/Top Events	After Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
TUN	CONSTRUCTION-TUNNELLING INCIDENTS						
01	1.Face instability 2.High surface settlements	Unlike	2	Consider	2	4	Accept
02	1.Heave of ground 2.Uplift 3.Blow out	Unlike	2	Consider	2	4	Accept
03	1.Ground swelling (expected as very low)	Unlike	2	Consider	2	4	Accept
04	1.Side wall collapse of twin tunnels	Unlike	2	Consider	2	4	Accept
05	1.Failure of segment lining 2.Collapse of tunnel	Unlike	2	Consider	2	4	Accept
06	1.Collapse of tunnel	Unlike	2	Consider	2	4	Accept
07	1.Uncontrolled water inflow into the cutter head chamber	Unlike	2	Consider	2	4	Accept
08	1.Segment floating	Unlike	2	Consider	2	4	Accept

Table 5.11.38 Risk assessment after mitigation for EPB TBM tunnels-maintenance

EPB TBM TUNNEL WORKS							
Item No	Hazards/Top Events	After Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
INC	CONSTRUCTION-MAINTENANCE						
01	1.Frequent change of cutting tools	Likely	4	Insig.	1	4	Accept
02	1.Trapped in confined space	Likely	4	Insig.	1	4	Accept
03	1.Trapped in confined space 2.Trapped under collapse 3.Suffocation	V.Unlike	1	Serious	3	3	Accept
04	1.Trapped in confined space 2.Suffocation 3.Decompression sickness	V.Unlike	1	Serious	3	3	Accept

Table 5.11.39 Risk assessment after mitigation for EPB TBM tunnels - tunnel installations

EPB TBM TUNNEL WORKS							
Item No	Hazards/Top Events	After Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
INS	CONSTRUCTION-TUNNEL INSTALLATIONS						
01	1.Electrical installation out of order	Unlikely	2	Consider	2	4	Accept
02	1.Lighting system out of order	Unlikely	2	Consider	2	4	Accept
03	1.Water supply system out of order	Unlikely	2	Consider	2	4	Accept
04	1.Ventilation system out of order	Unlikely	2	Consider	2	4	Accept
05	1.Communication system out of order	Unlikely	2	Consider	2	4	Accept
06	1.Fire fighting installations missing	Unlikely	2	Consider	2	4	Accept
07	1.First aid installations missing	Unlikely	2	Consider	2	4	Accept

Table 5.11.40 Risk assessment after mitigation for EPB TBM tunnels - structural hazards at shaft

EPB TBM TUNNEL WORKS							
Item No	Hazards/Top Events	After Mitigation					
		Frequency of Occurrence		Consequence		Risk Class	
		Desc.	Freq.	Severity		Rating	Accept
STR	CONSTRUCTION-STRUCTURAL HAZARDS AT SHAFT						
01	1.Failure at the foundation of shaft	V.Unlike	1	Severe	4	4	Accept
02	1.Failure at foundation of side wall	V.Unlike	1	Severe	4	4	Accept
03	1.Failure of piles	V.Unlike	1	Severe	4	4	Accept
04	1.Failure of support system (Prestressed anchors)	V.Unlike	1	Severe	4	4	Accept
05	1.Collapse of shaft	V.Unlike	1	Severe	4	4	Accept

Table 5.11.41 Risk Register for EPB TBM tunnels - accidents in tunneling

EPB TBM TUNNELS RISK REGISTER																										
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation							Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
										Frequency of Occurrence		Consequence		Risk Class					Frequency of Occurrence		Consequence		Risk Class				
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Desc.	H	S	E	Desc.	Freq.	Class	Severity	Rating	Accept				Desc.	Freq.	Severity		Rating	Accept			
ACC	CONSTRUCTION-ACCIDENTS IN TUNNELLING																									
	Confined Space																									
01	1.Too narrow space 2.Lack of escape 3.Lack of skill/competency	X	X		1.Trapped 2.Suffocation	F		X		Occasion	3	S	Serious	3	9	Unwant	1.Procedure	1.Certified workers 2.Training 3.Permit to work	V.Unlike	1	Serious	3	3	Accept	1.Const.	Const. Period	In progress
	TBM																									
02	1.Rock fall 2.Fall down 3.Uncertified operator	X	X	X	1.Crushed 2.Trapped	F		X		Occasion	3	S	Serious	3	9	Unwant	1.Operation as per manual 2.PPE 3.Access ladder	1.Certified operator	V.Unlike	1	Serious	3	3	Accept	1.Const.	Const. Period	In progress
	Belt Conveyor																									
03	1.Loose rock 2.Unguarded machinery 3.Uncertified operator 4.Lack of awareness	X	X	X	1.Crushed 2.Trapped	F		X		Occasion	3	S	Serious	3	9	Unwant	1.Cover to dangereous machine parts 2.Emergency off switch	1.Test/inspection 2.Certified operator 3.Training	V.Unlike	1	Serious	3	3	Accept	1.Const.	Const. Period	In progress
	Segment Erection																									
04	1.Uncertified operator 2.Mechanical breakdown 3.Lack of awareness	X	X	X	1.Crushed 2.Knocked down	F		X		Occasion	3	S	Serious	3	9	Unwant	1.Certified operator 2.No entry into danger zone 3.Continuous collaboration 4.Proper PPE	1.Training to operator/crew 2.Instructions 3.Tool box 4.Visual contact with operator	V.Unlike	1	Serious	3	3	Accept	1.Const.	Const. Period	In progress
	Tunnel Transport																									
05	1.Uncertified operator 2.Damaged tracks 3.Deformation of rolling stock 4.Overspeeding 5.De-railing of rolling stock	X	X	X	1.Crushed 2.Trapped	F		X		Occasion	3	S	Serious	3	9	Unwant	1.Certified operator 2.Maintenance/repair tracks 3.Maintenance/repair rolling stock 4.Speed limit 5.Speed alarm	1.Training to operator 2.Maintenance crew 3.Keep safe speed as max 10 km/h	V.Unlike	1	Serious	3	3	Accept	1.Const.	Const. Period	In progress
06	1.Uncertified operator 2.Misuse of locomotive 3.Overspeeding	X	X	X	1.Crushed 2.Trapped 3.Run into	F		X		Occasion	3	S	Serious	3	9	Unwant	1.Certified operator 2.Speed limit 3.Speed alarm 4.Warning light at work area in tunnel	1.Training to operator 2.Instructions to operator 3.Tool box to tunnel workers 4.No work on rail track 5.Keep safe speed as max 10 km/h	V.Unlike	1	Serious	3	3	Accept	1.Const.	Const. Period	In progress

Table 5.11.41 Risk Register for EPB TBM tunnels - accidents in tunneling – Continued

EPB TBM TUNNELS RISK REGISTER																											
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation							Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
										Frequency of Occurrence		Consequence		Risk Class					Frequency of Occurrence		Consequence		Risk Class				
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Desc.	H	S	E	Desc.	Freq.	Class	Severity	Rating	Accept				Desc.	Freq.	Severity		Rating	Accept			
ACC	CONSTRUCTION-ACCIDENTS IN TUNNELLING																										
	Toxic Gases																										
07	1.Diffusion of gases from ground 2.Spreading of gases 3.Lack of detection/alarm 4.Lack of awareness 5.Lack of emergency response	X	X	X	1.Irritation 2.Burn 3.Injury 4.Fatality	F		X		Unlikely	2	S	Severe	4	8	Unwant	1.Survey for gases 2.Detection of gases 3.Alarm levels for critical concentrations 4.Sufficient ventilation as per BS6164 5.Emergency response 6.Special PPE/masks 7.First aid/oxygen bottle 8.Medical care	1.TBM gas detection system 2.Additional gas detection system 3.Periodical maintenance 4.Periodical test on equipment 5.Emergency response plan 6.Training/drills	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress
	Explosive Gases																										
08	1.Diffusion of gases from ground 2.Spreading of gases 3.Lack of detection/alarm 4.Lack of awareness 5.Lack of emergency response	X	X	X	1.Explosion 2.Fire 3.Fatality	F		X		Unlikely	2	S	Severe	4	8	Unwant	1.Survey for gases 2.Detection of gases 3.Alarm levels for critical concentrations 4.Sufficient ventilation as per BS6164 5.Emergency response 6.Special PPE/masks 7.First aid/oxygen bottle 8.Fire fighting	1.TBM gas detection system 2.Additional gas detection system 3.Periodical maintenance 4.Periodical test on equipment 5.Emergency response plan 6.Training/drills 7.Liaison with Authorities	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress
	Chemicals																										
09	1.Spill of chemicals 2.Spreading of chemicals 3.Contact with chemicals 4.Lack of awareness	X	X	X	1.Irritation 2.Burn 3.Injury	SI		X		Occasion	3	S	Consd.	2	6	Unwant	1.Detection of gases 2.Alarm levels for critical concentrations 3.Sufficient ventilation as per BS6164 4.Emergency response 5.Special PPE/masks 6.MSDS/First aid 7.Medical care	1.TBM gas detection system 2.Additional gas detection system 3.Periodical maintenance 4.Periodical test on equipment 5.Emergency response plan 6.Training/drills	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress

Table 5.11.42 Risk Register for EPB TBM tunnels – accidents

EPB TBM TUNNELS RISK REGISTER																												
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation						Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
										Frequency of Occurrence		Consequence		Risk Class				Frequency of Occurrence		Consequence		Risk Class				
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Desc.	H	S	E	Desc.	Freq.	Class	Severity	Rating	Accept			Desc.	Freq.	Severity		Rating	Accept			
ACC	CONSTRUCTION-ACCIDENTS																											
	Running Trains																											
01	1.Running trains 2.Unrestricted access 3.No signal	X	X	X	1.Struck/Crashed 2.Knocked down	F		X		Occasion	3	S	Serious	3	9	Unwant	1.Perimeter fence 2.Controlled crossing 3.Safety signs	1.Induction 2.Special training	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress
	Overhead HV Power Lines																											
02	1.Induction 2.Arching 3.Lack of skill/competency	X	X	X	1.Electrical shock 2.Burn by arching	F		X		Occasion	3	S	Serious	3	9	Unwant	1.Implement TS HSE Plan	1.Induction 2.Special training 3.Permit to work	V.Unlike	1	Serious	3	3	Accept	1.Const.	Const. Period	In progress
	False Currents																											
03	1.Live power lines 2.False currents into ground	X	X	X	1.Electrical shock 2.Burn by arching	F		X		Occasion	3	S	Serious	3	9	Unwant	1.Survey of cables 2.Cancel cables 3.Remove cables 4.Training	1.Induction 2.Special training 3.Permit to work	V.Unlike	1	Serious	3	3	Accept	1.Const.	Const. Period	In progress
	Electrical Works																											
04	1.Induction/arching from HV 2.Arching 3.Live power lines 3.Direct contact 4.Lack of skill/competency	X	X	X	1.Electrical shock 2.Burn by arching	F		X		Occasion	3	S	Severe	4	12	Unwant	1.Procedure	1.Test/inspection certificate by authority 2.Certified electrician 3.Training 4.Permit to work	V.Unlike	1	Severe	4	4	Accept	1.Const.	Const. Period	In progress
	Equipments																											
05	1.Moving equipment 2.Mechanical failure 3.Uncertified operator 4.Lack of awareness	X	X	X	1.Trapped 2.Struck/Crashed 3.Knocked down	F		X		Occasion	3	S	Severe	4	12	Unwant	1.Procedure	1.Test/inspection certificate by authority 2.Certified operator 3.Training 4.Permit to work	V.Unlike	1	Severe	4	4	Accept	1.Const.	Const. Period	In progress
	Heavy Lifting																											
06	1.Struck by other equipment 2.Mechanical failure 3.Unbalanced equipment 4.Lack of skill/competency	X	X	X	1.Struck/Crashed 2.Knocked down	F		X		Occasion	3	S	Severe	4	12	Unwant	1.Procedure	1.Test/inspection certificate by authority 2.Certified operator 3.Training 4.Permit to work	V.Unlike	1	Severe	4	4	Accept	1.Const.	Const. Period	In progress
	Work at Height																											
07	1.Struck by other equipment 2.Failure of platform 3.Unsafe platform 4.Lack of skill/competency	X	X	X	1.Fall down 2.Struck by falling object	F		X		Occasion	3	S	Severe	4	12	Unwant	1.Procedure	1.Test/inspection certificate by authority 2.Certified workers 3.Training 4.Permit to work	V.Unlike	1	Severe	4	4	Accept	1.Const.	Const. Period	In progress
	Earthworks																											
08	1.Struck by other equipment 2.Mechanical failure 3.Unbalanced equipment 4Lack of skill/competency	X	X	X	1.Trapped 2.Struck/Crashed 3.Knocked down	F		X		Occasion	3	S	Severe	4	12	Unwant	1.Procedure	1.Test/inspection certificate by authority 2.Certified operators 3.Training 4.Permit to work	V.Unlike	1	Severe	4	4	Accept	1.Const.	Const. Period	In progress

Table 5.11.42 Risk Register for EPB TBM tunnels - accidents-Continued

EPB TBM TUNNELS RISK REGISTER																												
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation							Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Desc.	H	S	E	Frequency of Occurrence		Consequence		Risk Class					Frequency of Occurrence		Consequence		Risk Class				
										Desc.	Freq.	Class	Severity	Rating	Accept				Desc.	Freq.	Severity		Rating	Accept			
ACC	CONSTRUCTION-ACCIDENTS																											
	Supervision/Inspect./Survey																											
09	1.Moving equipment 2.Lack of awareness	X		X	1.Trapped 2.Struck/Crashed 3.Knocked down 4.Trip	F		X		Occasion	3	S	Serious	3	9	Unwant	1.Instructions	1.Training	V.Unlike	1	Serious	3	3	Accept	1.Const.	Const. Period	In progress
	Cold Work																											
10	1.Breakdown of equipment 2.Misuse of equipment 3.Lack of awareness	X	X		1.Struck/Crushed 2.Knocked down	F		X		Occasion	3	S	Serious	3	9	Unwant	1.Procedure	1.Qualified workers 2.Training	V.Unlike	1	Serious	3	3	Accept	1.Const.	Const. Period	In progress
	Hot Work																											
11	1.Breakdown of equipment 2.Misuse of equipment 3.Lack of awareness	X	X		1.Burn	SI		X		Occasion	3	S	Consider	2	6	Unwant	1.Procedure	1.Qualified workers 2.Training	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress
	Hand Tools																											
12	1.Breakdown of equipment 2.Misuse of equipment 3.Lack of awareness	X	X		1.Crushed	SI		X		Occasion	3	S	Consider	2	6	Unwant	1.Procedure	1.Qualified workers 2.Training	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress
	Manual Handling																											
13	1.Lack of awareness	X	X		1.Crushed	SI		X		Occasion	3	S	Consider	2	6	Unwant	1.Instructions	1.Training	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress
	Pipe/Pump/Stationery Plant																											
14	1.Rupture of pipe/pump/plant 2.Lack of awareness	X	X		1.Crashed 2.Knocked down	SI		X		Occasion	3	S	Consider	2	6	Unwant	1.Instructions	1.Training	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress
	Compressed Air																											
15	1.Breakdown of equipment 2.Rupture of pipe 3.Misuse of equipment 4.Lack of awareness	X	X		1.Exposure to high pressure	SI		X		Occasion	3	S	Consider	2	6	Unwant	1.Procedure	1.Qualified workers 2.Training	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress

Table 5.11.43 Risk Register for EPB TBM tunnels – fire

EPB TBM TUNNELS RISK REGISTER																												
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation							Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
										Frequency of Occurrence		Consequence		Risk Class					Frequency of Occurrence		Consequence		Risk Class				
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E	Desc.	Freq.	Class	Severity	Rating	Accept				Desc.	Freq.	Severity		Rating	Accept			
FIRE	CONSTRUCTION-FIRE																											
01	1.Combustibles : Normal 2.Flammables : Low 3.Ignition sources: Normal 4.Control means : Normal	X	X	X	1.Fire in tunnel	1.Fatality 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X	Occasion	3	S	Severe	4	12	Unwant	1.Control means: High 2.Security 3.Fire fighting 4.Liaison with fire brigade 5.Emergency plan	1.Inspection of control means 2.Fire fighting drills 3.Emergency evacuation drills 4.Training/awereness 5.Insurance	V.Unlike	1	Severe	4	4	Accept	1.Const	Const. Period	In progress
02	1.Combustibles : Normal 2.Flammables : Low 3.Ignition sources: Normal 4.Control means : Normal	X	X	X	1.Fire at shaft	1.Fatality 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X	Occasion	3	S	Severe	4	12	Unwant	1.Control means: High 2.Security 3.Fire fighting 4.Liaison with fire brigade 5.Emergency plan	1.Inspection of control means 2.Fire fighting drills 3.Emergency evacuation drills 4.Training/awereness 5.Insurance	V.Unlike	1	Severe	4	4	Accept	1.Const	Const. Period	In progress
03	1.Combustibles : Normal 2.Flammables : Low 3.Ignition sources: Normal 4.Control means : Normal	X	X	X	1.Fire at area	1.Fatality 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X	Occasion	3	S	Severe	4	12	Unwant	1.Control means: High 2.Security 3.Fire fighting 4.Liaison with fire brigade 5.Emergency plan	1.Inspection of control means 2.Fire fighting drills 3.Emergency evacuation drills 4.Training/awereness 5.Insurance	V.Unlike	1	Severe	4	4	Accept	1.Const	Const. Period	In progress
04	1.Spreading of fire outside	X	X	X	1.Fire at Community/ Built Environment	1.Fatality 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X	Occasion	3	S	Severe	4	12	Unwant	1.Control means: High 2.Security 3.Fire fighting 4.Liaison with fire brigade 5.Emergency plan	1.Inspection of control means 2.Fire fighting drills 3.Emergency evacuation drills 4.Training/awereness 5.Insurance	V.Unlike	1	Severe	4	4	Accept	1.Const	Const. Period	In progress

Table 5.11.44 Risk Register for EPB TBM tunnels – flood

EPB TBM TUNNELS RISK REGISTER																												
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation							Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
										Frequency of Occurrence		Consequence		Risk Class					Frequency of Occurrence		Consequence		Risk Class				
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E	Desc.	Freq.	Class	Severity	Rating	Accept				Desc.	Freq.	Severity		Rating	Accept			
FLD	CONSTRUCTION-FLOOD																											
01	1.Surface runoff LE design 2.Dyke level LT design flood WL 3.Failure of dyke 4.No early warning 5.Insufficient emergency plan 6.No emergency rescue	X	X	X	1.Flooding of shaft and tunnel	1.Inundation of tunnel 2.Short circuit 3.Fatality 4.Damage to env. 5.Damage to eq. 6.Interruption of work 7.Loss of time 8.Economic Loss		X	X	Occasion	3	S	Severe	4	12	Unwant	1.Hydrological study to estimate flood Q 2.Hydraulic study to estimate flood WL 3.Dyke level with adequate free board 4.Sound dyke 5.Early warning 6.Emergency evacuation plan 7.Emergency rescue plan	1.Review studies 2.Repair/maintenance dyke 3.Follow weather forecasts 4.Watching for early warning 5.Emergency evacuation drills 6.Emergency rescue drills 7.Training/awereness 8.Insurance	V.Unlike	1	Severe	4	4	Accept	1.DSG 2.Const.	Const. Period	In progress
02	1.Surface runoff GT design 2.No early warning 3.Insufficient emergency plan 4.No emergency rescue	X	X	X	1.Flooding of shaft and tunnel	1.Inundation of tunnel 2.Short circuit 3.Fatality 4.Damage to env. 5.Damage to eq. 6.Interruption of work 7.Loss of time 8.Economic Loss		X	X	Unlike	2	S	Disaster	5	10	Unwant	1.Hydrological study to estimate flood Q 2.Hydraulic study to estimate flood WL 3.Dyke level with adequate free board 4.Sound dyke 5.Early warning 6.Emergency evacuation plan 7.Emergency rescue plan	1.Follow weather forecasts 2.Watching for early warning 3.Emergency evacuation drills 4.Emergency rescue drills 5.Training/awereness 6.Insurance	V.Unlike	1	Severe	4	4	Accept	1.DSG 2.Const.	Const. Period	In progress

Table 5.11.45 Risk Register for EPB TBM tunnels – earthquake

EPB TBM TUNNELS RISK REGISTER																												
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation						Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
										Frequency of Occurrence		Consequence		Risk Class				Frequency of Occurrence		Consequence		Risk Class				
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E	Desc.	Freq.	Class	Severity	Rating	Accept			Desc.	Freq.	Severity		Rating	Accept			
EQ	CONSTRUCTION-EARTHQUAKE																											
01	1.Earthquake LE Design 2.Lack of EQ resistance 3.Design mistake	X	X	X	1.Catastrophic failure by EQ	1.Damage to tunnel lining 2.Collapse of tunnel 3.Damage to BE 4.Fatality 5.Interruption of work 6.Loss of time 7.Economic Loss		X	X	Unlikely	2	C	Disaster	5	10	Unwant	1.Seismic design in accordance with req. 2.Tunnel construction facility as per BS 6164 3.Insurance cover	1.Design check/verification 2.Emergency Response Plan 3.Emergency evacuation drill 4.Liaison with Authorities	V. Unlike	1	Severe	4	4	Accept	1.PM	Const. Period	In progress
02	1.Earthquake GT Design			X	1.Catastrophic failure by EQ	1.Damage to tunnel lining 2.Collapse of tunnel 3.Damage to BE 4.Fatality 5.Interruption of work 6.Loss of time 7.Economic Loss		X	X	V. Unlike	1	C	Disaster	5	5	Unwant	1.Tunnel construction facility as per BS 6164 2.Insurance cover	1.Design check/verification 2.Emergency Response Plan 3.Emergency evacuation drill 4.Liaison with Authorities	V. Unlike	1	Severe	4	4	Accept	EMP	Const. Period	In progress

Table 5.11.46 Risk Register for EPB TBM tunnels - alignment conflicts

EPB TBM TUNNELS RISK REGISTER																													
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation							Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E	Frequency of Occurrence		Consequence		Risk Class					Frequency of Occurrence		Consequence		Risk Class				
										Desc.	Freq.	Class	Severity	Rating	Accept				Desc.	Freq.	Severity		Rating	Accept			
ALIGN	CONSTRUCTION-ALIGNMENT CONFLICTS																												
01	1.Movement of base point 2.Mis-survey 3.Alignment conflicts	X	X	X	1.Deviation from alignment	1.Interruption of work 2.Corrective work 3.Loss of time 4.Economic Loss				Occasion	3	T	Serious	3	9	Unwant	1.Protection of base points 2.Cross check of survey system 3.Periodical calibration of equipment 4.High precision survey 5.More frequent survey	1.Regular checks of survey results 2.Monitoring of tunnel deformations	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress
02	1.Boulders 2.Tree trunk 3.Hindrance in front of tunnel face 4.Blocking of cutter head 5.Breakdown of TBM 6.Interruption of tunnelling	X	X	X	1.Instability of tunnel	1.Injury 2.Damage to BE 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X	Occasion	3	T	Serious	3	9	Unwant	1.Sufficient cutting tools 2.TBM to break minor boulders within cutting head 3.Sensitive control of face pressure 4.Conditioning of soil pulp if necessary 5.Treatment in case of very unfavourable ground conditions	1.TBM O&M Manual 2.Stop TBM, if boulders cannot be crushed by disc cutter 3.Stabilization of face 4.Apply air pressure 5.Empty cutting head chamber 6.Seal face if air consumption too high 7.Enter into chamber 8.Boulder to be removed	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress
03	1.Unknown/unidentified well/borehole/cavity 2.Void not completely backfilled 3.TBM operation with compressed air	X	X	X	1.Very high settlements 2.Blow out 3.Tunnel face instability	1.Injury 2.Damage to BE 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X	Occasion	3	T	Serious	3	9	Unwant	1.Survey of wells 2.Geophysical investigation 3.Backfill and closure of wells, boreholes, cavity 4.New boreholes to be kept in safe distance	1.Stabilisation of tunnel face 2.Immediate backfill of well or borehole 3.Grouting at tunnel face if suitable	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress
04	1.Lack of condition survey 2.Unknown/unidentified deep foundations 3.Breakdown of TBM 4.Interruption of tunnelling	X	X	X	1.Damage to deep foundations	1.Injury 2.Damage to BE 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X	Occasion	3	T	Serious	3	9	Unwant	1.Condition survey 2.Identify deep foundations 3.Stabilisation of tunnel face	1.Stabilisation/ adaptation of foundation if possible 2.Removal of redundant foundation at tunnel face	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress
05	1.Backfilled harbour	X	X	X	1.Problems during tunnelling (3+400-3+700)	1.Damage to BE 2.Interruption of work 3.Loss of time 4.Economic Loss		X	X	Occasion	3	T	Serious	3	9	Unwant	1.Condition survey 2.Identify possible problems 3.Stabilisation of tunnel face	1.Detailed study	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress

Table 5.11.47 Risk Register for EPB TBM tunnels - tunnelling incidents

EPB TBM TUNNELS RISK REGISTER																											
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation						Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E	Frequency of Occurrence		Consequence		Risk Class				Frequency of Occurrence		Consequence		Risk Class				
										Desc.	Freq.	Class	Severity	Rating	Accept			Desc.	Freq.	Severity		Rating	Accept			
TUN	CONSTRUCTION-TUNNELLING INCIDENTS																										
01	1.Sand lenses or sandy layers with low or no cohesion with narrow grain size distribution at top of tunnel excavation 2.Non cohesive loose soils 3.Mixed face conditions 4.Significant strength difference btw materials at excavation face 5.Overcutting 6.Hindrance at tunnel face 7.Insufficient face pressure 8.Lack of competence 9.Breakdown of equipment	X	X	X	1.Face instability 2.High surface settlements	1.Injury 2.Damage to BE 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X	Occasion	3	T	Serious	3	9	Unwant	1.Sensitive control of face pressure 2.Conditioning of soil pulp if necessary 3.Treatment in case of very unfavourable ground conditions 4.Monitoring 5.Application of trigger levels	1.TBM O&M Manual 2.Measures for settlement reduction 3.Increase of face pressure 4.Relation btw cutter head rotation and velocity of stroke 5.Condition of soil within cutter head chamber 6.Ground treatment	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress
02	1.Non-cohesive soils with high permeability 2.TBM in semi-closed mode or maintenance mode 3.Compressed air is used 4.Too high face pressure 5.Lack of competence 6.Breakdown of equipment	X	X	X	1.Heave of ground 2.Uplift 3.Blow out	1.Injury 2.Damage to BE 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X	Occasion	3	T	Serious	3	9	Unwant	1.Avoid semi-open mode within non-cohesive soil 2.Select allowable face pressure 3.Maintain face pressure below that 4.Avoid compressed air in areas where the foundation of buildings major utilities or wells are in a distance of less the 4 m	1.Decrease of face pressure	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress
03	1.Cohesive soil with high swelling index	X	X	X	1.Ground swelling (expected as very low)	1.Damage to BE		X	X	Occasion	3	T	Serious	3	9	Unwant	1.Controllable overcutter	1.TBM O&M Manual 2.Measures for settlement reduction	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress
04	1.Insufficient side wall between tunnels 2.Excessive ground deformations	X	X	X	1.Side wall collapse of twin tunnels	1.Interruption of tunnelling 2.Fatality		X	X	Occasion	3	T	Serious	3	9	Unwant	1.Adequate cover and overburden 2.Treatment in case of very unfavourable ground conditions 3.Backfill grouting parallel to excavation 4.Monitoring 5.Application of trigger levels	1.TBM O&M Manual 2.Measures for settlement reduction 3.Monitoring tunnel deformations	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress

Table 5.11.47 Risk Register for EPB TBM tunnels - tunnelling incidents-Continued

EPB TBM TUNNELS RISK REGISTER																											
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation							Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
										Frequency of Occurrence		Consequence		Risk Class					Frequency of Occurrence		Consequence		Risk Class				
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E	Desc.	Freq	Class	Severity	Rating	Accept				Desc.	Freq	Severity	Rating	Accept				
TUN	CONSTRUCTION-TUNNELLING INCIDENTS																										
05	1.Excessive surcharge load on tunnel 2.Poor geological conditions 3.Face completely in soft ground 4.Under critical structures 5.Stoppage of tunnelling for long periods 6.Insufficient segment strength	X	X	X	1.Failure of segment lining 2.Collapse of tunnel	1.Injury 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X	Occasion	3	T	Serious	3	9	Unwant	1.Adequate cover and overburden 2.Treatment in case of very unfavourable ground conditions 3.Backfill grouting parallel to excavation 4.Continuous tunnelling 5.Proper segment quality 6.Monitoring	1.Measures for settlement reduction 2.Monitoring tunnel deformations 3.w/o compressed air for quick maintenance	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress
06	1.Excessive surcharge load on tunnel 2.Poor geological conditions 3.Face completely in soft ground 4.Under critical structures 5.Stoppage of tunnelling for long periods 6.Insufficient segment strength	X	X	X	1.Collapse of tunnel	1.Injury 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X	Occasion	3	T	Serious	3	9	Unwant	1.TBM damage to be repaired from outside	1.Stoppage of tunnelling 2.Access shaft	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress
07	1.Cohesionless ground at tunnel face 2.Sand or coarse grained soils 3.Consistency of soil is not plastic to semi-liquid 4.No proper soil pulp to seal tunnel face 5.Permeability of soil too high to set up a proper face pressure	X	X	X	1.Uncontrolled water inflow into the cutter head chamber (1+950-2+650)	1.Interruption of tunnelling		X	X	Occasion	3	T	Serious	3	9	Unwant	1.Conditioning of soil with foam,polymers or bentonite	1.Stop TBM 2.Close screw conveyor 3.Adopt conditioning of soil 4.Restart TBM 5.Slush pump at end of screw conveyor	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress
08	1.Uncontrolled water inflow 2.Delays with backfill grouting 3.Retardation of setting time of backfill grout	X	X	X	1.Segment floating	1.Interruption of tunnelling		X	X	Occasion	3	T	Serious	3	9	Unwant	1.Control of infow water 2.Backfill grouting parallel to excavation 3.Grout mix in conformity with requirements	1.Monitoring deviations	Unlike	2	Consider	2	4	Accept	1.Const	Const. Period	In progress

Table 5.11.48 Risk Register for EPB TBM tunnels – maintenance

EPB TBM TUNNELS RISK REGISTER																													
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation							Mitigation	Proposed Actions	After Mitigation							In Charge	Action Due	Status
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E	Frequency of Occurrence		Consequence		Risk Class					Frequency of Occurrence		Consequence		Risk Class					
										Desc.	Freq.	Class	Severity	Rating	Accept				Desc.	Freq.	Severity		Rating	Accept			
INC	CONSTRUCTION-MAINTENANCE																												
	Change of cutting tools																												
01	1.Difficult ground conditions 2.Less durable cutting tools 3.Inappropriate operation of TBM 4.Insufficient maintenance 5.High abrasion of cutting tools	X	X	X	1.Frequent change of cutting tools	1.Interruption of work 2.Loss of time 3.Economic loss		X		Likely	4	T	Consider	2	8	Unwant	1.Long durable cutting tools 2.Adjustment of torque and thrust to reduce wearing 3.Regular maintenance 4.Easy replacement type cutting tools	1.TBM O&M Manual	Likely	4	Insig.	1	4	Accept	1.Const	Const. Period	In progress
02	1.Entry into cutting head chamber 2.Change of cutting tools	X	X	X	1.Trapped in confined space	1.Injury 2.Interruption of work 3.Loss of time 4.Economic loss		X		Likely	4	S	Consider	2	8	Unwant	1.Change of cutting tools from backside of cutter head 2.Permit to work	1.TBM O&M Manual 2.Change during maintenance shift	Likely	4	Insig.	1	4	Accept	1.Const	Const. Period	In progress
03	1.Entry into cutting head chamber 2.Changing from backside is not possible 3.Entry into front space 4.Change of cutting tools	X	X	X	1.Trapped in confined space 2.Trapped under collapse 3.Suffocation	1.Fatality 2.Interruption of work 3.Loss of time 4.Economic loss		X		Unlikely	2	S	Serious	3	6	Unwant	1.Change under less risky soil conditions 2.Semi-closed mode if possible 3.Scaffolding 4.Permit to work	1.TBM O&M Manual 2.Proper and regular maintenance of cutting tools 3.Safe locations for stoppafe of TBM to be defined in advance	V.Unlike	1	Serious	3	3	Accept	1.Const	Const. Period	In progress
04	1.Entry into cutting head chamber 2.Changing from backside is not possible 3.Entry into front space 4.Sensitive structures above tunnel 5.High face pressure 6.Change of cutting tools under pressure 7.Sudden decompression	X	X	X	1.Trapped in confined space 2.Suffocation 3.Decompression sickness	1.Fatality 2.Interruption of work 3.Loss of time 4.Economic loss		X		Unlikely	2	S	Serious	3	6	Unaccept	1.Change under less risky soil conditions 2.Treatment of ground 3.Semi-closed mode if possible 4.Scaffolding 5.PPE for work under pressure 6.Gradual pressure change 7.Compressed air equipment 8.Permit to work	1.TBM O&M Manual 2.Proper and regular maintenance of cutting tools 3.Safe locations for stoppafe of TBM to be defined in advance	V.Unlike	1	Serious	3	3	Accept	1.Const	Const. Period	In progress

Table 5.11.49 Risk Register for EPB TBM tunnels - tunnel installations

EPB TBM TUNNELS RISK REGISTER																												
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation							Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E	Frequency of Occurrence		Consequence		Risk Class					Frequency of Occurrence		Consequence		Risk Class				
										Desc.	Freq.	Class	Severity	Rating	Accept				Desc.	Freq.	Severity		Rating	Accept			
INS	CONSTRUCTION-TUNNEL INSTALLATIONS																											
01	1.Unsuitable installation 2.Damage 3.Lack of maintenance 4.Lack of repair	X	X	X	1.Electrical installation out of order	1.Power cut off 2.Accident 3.Interruption of work 4.Loss of time 5.Economic Loss		X		Occasion	3	S	Serious	3	9	Unwant	1.Suitable installation 2.Periodical maintenance 3.Quick repairs 4.Spare parts	1.Periodical check/test 2.Report defects	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress
02	1.Unsuitable system 2.Damage 3.Lack of maintenance 4.Lack of repair	X	X	X	1.Lighting system out of order	1.Insufficient illumination 2.Accident 3.Interruption of work 4.Loss of time 5.Economic Loss		X		Occasion	3	S	Serious	3	9	Unwant	1.Suitable system 2.Special lighting at critical locations 3.Flashing warning lights at dangereous locations 4.Emergency lights 5.Waterproof installations 6.Periodical maintenance 7.Quick repairs	1.Periodical check of eq. 2.Battery lights in tunnel 3.Diesel set in operation	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress
03	1.Unsuitable equipment 2.Damage to eq. 3.Lack of repair 4.Lack of maintenance	X	X	X	1.Water supply system out of order	1.Water supply off 2.Interruption of work 3.Instability 4.Loss of time 5.Economic Loss		X		Occasion	3	S	Serious	3	9	Unwant	1.Suitable installation 2.Periodical maintenance 3.Quick repairs 4.Spare parts	1.Water storage tanks	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress
04	1.Unsuitable system 2.Insufficient capacity 3.Power cut off 4.Damage to eq. 5.Lack of repair 6.Lack of maintenance	X	X	X	1.Ventilation system out of order	1.Insufficient ventilation 2.Interruption of work 3.Loss of time 4.Economic Loss		X		Occasion	3	S	Serious	3	9	Unwant	1.Suitable system 2.Diesel set 3.Automatic switch to diesel 4.Spare parts 5.Quick repair of damage 6.Periodical maintenance	1.Air ducts close to face 2.Seal joints properly 3.Adequate support to ducts 4.Periodical check of eq. 5.Evacuation of tunnel	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress

Table 5.11.49 Risk Register for EPB TBM tunnels - tunnel installations-Continued

EPB TBM TUNNELS RISK REGISTER																												
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation							Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E	Frequency of Occurrence		Consequence		Risk Class					Frequency of Occurrence		Consequence		Risk Class				
										Desc.	Freq.	Class	Severity	Rating	Accept				Desc.	Freq.	Severity		Rating	Accept			
INS	CONSTRUCTION-TUNNEL INSTALLATIONS																											
05	1.Unsuitable system 2.Damage 3.Lack of maintenance 4.Lack of repair	X	X	X	1.Communication system out of order	1.Lack of communication 2.Lack of emergency response 3.Injury 4.Interruption of work		X		Occasion	3	S	Serious	3	9	Unwant	1.Effective communication means 2.Supplementary system 3.Periodical maintenance 4.Quick repairs 5.Spare parts	1.Periodical check/test 2.Report defects 3.Fix emergency rescue plan 4.Emergency drills	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress
06	1.Lack of care/awareness 2.Damage	X	X	X	1.Fire fighting installations missing	1.Lack of emergency response 2.Injury		X		Occasion	3	S	Serious	3	9	Unwant	1.Fire extinguishers 2.Masks	1.Periodical check 2.Report defects	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress
07	1.Lack of care/awareness 2.Damage	X	X	X	1.First aid installations missing	1.Lack of emergency response 2.Injury		X		Occasion	3	S	Serious	3	9	Unwant	1.First aid kits	1.Periodical check 2.Report defects	Unlikely	2	Consider	2	4	Accept	1.Const.	Const. Period	In progress

Table 5.11.50 Risk Register for EPB TBM tunnels - structural hazards at shaft

EPB TBM TUNNELS RISK REGISTER																													
Item No	Root Causes				Hazards/Top Events	Consequent Risks				Before Mitigation							Mitigation	Proposed Actions	After Mitigation						In Charge	Action Due	Status
	Initiating Events	Hum.	Mat./ Eq.	Ext.		Description	H	S	E	Frequency of Occurrence		Consequence		Risk Class					Frequency of Occurrence		Consequence		Risk Class				
										Desc.	Freq.	Class	Severity	Rating	Accept				Desc.	Freq.	Severity	Rating	Accept				
STR	CONSTRUCTION-STRUCTURAL HAZARDS AT SHAFT																												
01	1.Quick sand/boiling/piping 2.Heave of bottom of excavation	X	X	X	1.Failure at the foundation of shaft	1.Damage to env. 2.Interruption of work 3.Loss of time 4.Economic Loss		X	X	Unlikely	2	C	Severe	4	8	Unwant	1.Deep piles 2.Piles into impervious layer 3.Adequate FS against piping	1.Monitoring 2.Inspection/evaluation	V.Unlike	1	Severe	4	4	Accept	1.Const. 2.DSG	Const. Period	Complete
02	1.Insufficient support at foundation	X	X	X	1.Failure at foundation of side wall	1.Damage to env. 2.Interruption of work 3.Loss of time 4.Economic Loss		X	X	Unlikely	2	C	Severe	4	8	Unwant	1.Piles anchored into ground	1.Monitoring 2.Inspection/evaluation	V.Unlike	1	Severe	4	4	Accept	1.Const. 2.DSG	Const. Period	Complete
03	1.Insufficient material quality	X	X	X	1.Failure of piles	1.Damage to env. 2.Interruption of work 3.Loss of time 4.Economic Loss		X	X	Unlikely	2	C	Severe	4	8	Unwant	1.RC with C40 2.High workability 3.Suitable tremie concrete 4.QC on fresh concrete	1.Monitoring 2.Inspection/evaluation	V.Unlike	1	Severe	4	4	Accept	1.Const. 2.QA/QC	Const. Period	Complete
04	1.Insufficient material quality	X	X	X	1.Failure of support system (Prestressed anchors)	1.Damage to env. 2.Interruption of work 3.Loss of time 4.Economic Loss		X	X	Unlikely	2	C	Severe	4	8	Unwant	1.Prestressed anchoring 2.Adequate FS	1.Monitoring 2.Inspection/evaluation	V.Unlike	1	Severe	4	4	Accept	1.Const. 2.QA/QC	Const. Period	Complete
05	1.Excessive surcharge 2.Instability of side walls 3.Insufficient support system	X	X	X	1.Collapse of shaft	1.Injury 2.Damage to env. 3.Interruption of work 4.Loss of time 5.Economic Loss		X	X	Unlikely	2	C	Severe	4	8	Unwant	1.Compatible design with geotechnical requirements 2.Robust/sound design 3.Limit to surcharge load on slopes 4.Adequate FS including EQ	1.Design and development check/review 2.Special design study 3.Independent Design Verification (IDV) 4.Critical surcharge load	V.Unlike	1	Severe	4	4	Accept	1.Const. 2.DSG	Const. Period	In progress

CHAPTER 6

RESULTS AND CONCLUSIONS

Construction work is accepted as an occupational area with high risk in modern society. It is caused by combination of many reasons, such as high risk characteristic of construction work and low education level of construction workers. Besides, the competitive tendering system and extensive use of subcontractors are the other systemic factors contributing to raise construction works' risk level.
Today, OH&S has become an aspect that is nearly followed by media and is interested by many different parties including the community in addition to direct sides of the aspect. So, any longer, accident investigation is not only a crucial task for any major hazard industrial facility because accidents are expensive in terms of their direct and indirect costs, but as well as in terms of company's reputation.

Now, there is no doubt that health and safety matter is not alone a law's or regulation's or worker's matter but a matter directly related with organization and management. So occupational health and safety is managed by an effective occupational health and safety management system integrated with other managements systems such as quality and environment etc. as a whole in the organization.

The subject of this thesis: The whole process of "hazard identification, risk assessment and determining controls" is heart of the OH&S management system as a part of its "planning" stage. Although there are comprehensive standards, guides, codes of practice related with the development of an successful OH&S management system; the transient, unique, and complex nature of construction projects still makes safety management in construction industry exceptionally difficult. Most construction safety efforts are applied in an informal fashion under the premise that simply allocating more resources to safety management will improve site safety. Currently, there is no mechanism by which construction safety professionals may formally evaluate safety risk and select safety program elements for implementation. Fortunately, large firms have minimal impact from this issue since they have already owned the resources and infrastructure to implement an effective OH&S management system including, in large proportion, applicable

program elements. So the applications of OH&S management system for important projects by large firms in different construction trades has crucial importance as experienced documentations for health and safety professionals and managers.

This study is just held as moving from this issue. In the thesis, while, on one hand, the hazard identification, risk assessment and related determining controls aspects of occupational health and safety topic, within the framework of a safety management system are examined by carrying out a literature survey with specific emphasis on the standards, guidelines, codes of practices and other documents published by authorized institutions and national legislation related with the subject; on the other hand, the case study is carried out on the Marmaray Project, which is considered as one of the major transportation infrastructure projects in Turkey, and hence the results of a large application of the hazard identification, risk assessment and related determining controls aspects for the cut and cover underground station construction and for the tunnel construction are assessed and documented.

Anyway, the pressure of production targets, financial constraints and difficulties arising the specific nature of construction industry still continue to form obstacles for application of good standards and for achievement of a successful OH&S management system. In spite of that, moral, legal and economic necessities constitute a powerful incentive for organizations to strive for a high level of OH&S.

The literature survey emphasized on the standards, guidelines, codes of practices revealed that hazard identification, risk assessment and determining controls aspects are the part of an OH&S management system, where there is the least consistency in terminology. This situation creates difficulties to follow different sources of information at the same time and make synthesis. This difficulty will rise as the level of study gets deeper. It is sincerely expected that this inconsistency of terminology should be removed by authorized institutions. This confusion does not affect only scientific studies but, of course, the site applications of health and safety management. The two substantial terms, here to be mentioned, in which different approaches prevail in literature are “incident - accident” and “risk assessment”.

There are two main and different approaches for the definition of “incident” and “accident” terms between standards, guides and codes of practice. The first is the offer of OHSAS 18001:2007 etc., which considers the term of ”incident” as an umbrella for all occurrences, and so here, “accident” is accepted only as an “incident” which has given rise to injury, ill health or fatality; while an “incident” where

no injury, ill health, or fatality occurs is referred as “near miss”. The second approach is made by BS 8800:2004 etc., which defines “accident” as undesired event giving rise to death, ill health, injury, while “incident” is referred as only an event where no injury, ill health, or fatality occurs.

For the term of “risk assessment”, the first fundamental approach is followed by OHSAS 18001:2007 etc. and it differentiates “hazard identification”, “risk assessment” and “determining controls” processes as interrelated but separate executions. While BS 8800 etc., offers the second fundamental approach, and here, on the contrary of the first approach, the term of “risk assessment” is accepted as an entire process covering “hazard identification”, “risk assessment” and “determining controls” stages.

It is thought that as in the first approach, assuming “incident” as an umbrella term and defining other terms of “accident”, “near misses”, “unsafe acts”, “unsafe conditions” etc. for different specific occurrences provide a large scale of terms and capability of thinking in wide perspective for the area of occupational health and safety aspect.

It is also thought that , at least for an easy explanation, defining an umbrella term for the total of the “hazard identification”, “risk assessment” and “determining controls” processes is needed but it should not be “risk assessment” which causes confusion in explanation as in the second approach but, instead of it, a different term. On the other hand, it is thought that, as in the first approach, “hazard identification”, “risk assessment” and “determining controls” processes should be considered as interrelated but differentiated executions under a head topic which should be newly termed in a common consent.

The case study on cut and cover underground stations and tunnel construction is carried out for a project and for an organization in two separate construction site. So the results of the application obtained are specific and are not enough to make any generalization or to make comparisons of different applications about the hazard identification, risk assessment and determining controls processes within the framework of a safety management system. But, of course, as noting down the results, it would be possible to criticize the specific application in the light of the criteria of a successful OH&S management system and the current studies having been performed and hence new approaches having been developed for the application of OH&S management system in construction industry.

One of the new approaches for a successful OH&S management system in construction industry is related with “near miss” aspect. Near misses are the major source of useful information for safety management. So they are frequently referred as precursors of accidents. Despite of this, there is little knowledge on the characteristics of near misses, and on the use of this information in safety management. For instance, the analysis of the near miss occurrences for whether an injury case is not occurred by the control of worker himself or by preventive measures such as physical barriers undertaken by competent safety persons or an injury case is not occurred just by a chance reveal too much about the existing management system. If in a near miss occurrence, it is rescued from an injury case just by a chance, this certainly proves that there are clear failures in safety management and it requires immediate action. So it is recommended by researchers that an information system on near misses should be developed and integrated into a more comprehensive information system. In this respect, the European Council with “Seveso II Directive’96/82/EC“ made an explicit recommendation to report near misses to the Commission’s Major Accident Reporting System(MARS) in addition to mandatory requirements. All studies reveal that if near misses are reported, well analyzed and well learnt from them, then eventually, in a workplace, a reduction in the numbers of near misses, and a preceding reduction in the number of accidents are experienced. Besides that, it is offered by some researchers that in quantitative estimation of risks, if near miss occurrences are not considered, then it can result in significant under estimation of the real risk value. They assume “conventional” risk estimates which are based on only “top events” but not considering near misses together with these accidents undependable.

In the case study, it is found that the GN organization established a near miss reporting procedure and especially for last three years near misses are regularly reported. This is an approach consistent with the current developments in OH&S management system aspect. In this duration about 50 near miss report is documented. Despite of developed near miss reporting procedure by the organization, it is also noted in the case study that it is not performed a deep analysis on near miss occurrences and a systematic dissemination of information on near misses as feedback in the meaning of what the current researches recommend as mentioned above. It is noted that the organization is mainly based on, by knowing just at the beginning of OH&S management system establishment, the monitoring of

“non-conformities” which are defined as any deviation from relevant work standards, practices, procedures, legal requirements etc. in dissemination of information to prevent the accident occurrences. It is thought that near misses should be also used by well analyzing and extracting lessons from them in the same importance together with non-conformities in the system of dissemination of information to improve management system performance in workplace hence to take pro-active actions to prevent accidents.

As mentioned above, despite of existence of comprehensive standards, guides, codes of practice and literature related with the development of an successful OH&S management system; still there is no mechanism by which construction safety professionals may formally evaluate safety risk and select safety program elements for implementation. So studies have been going on by interested researchers to realize more accurate and consistent quantitative models to evaluate safety risks and select preventive safety program elements on which a common consent have been provided and hence have the capability of appliance formally and widely in construction industry.

In the case study, for hazard identification, risk assessment and determining controls, it is found that the GN Organization basically depends on its past experience, participation and consultation of workforce, experience of subcontractors and other organizations’ experience performed similar projects besides recommendations of codes of practice, guidelines and documentations published by competent agencies. A HAZID workshop which is multidisciplinary team is built for hazard identification, risk assessment and determining control processes planning. Risk assessment process is executed by semi-quantitative method of 5x5 risk matrix. It is understood that in the classification of frequency of occurrences and severity of consequences the Organization is, in general, based on the ITA (International Tunneling Association) recommendations. However, it should be noted that there are not documents containing details and notes related with HAZID workshop executions, in spite of the presence of comprehensive risk registers submitting all the results of HAZID workshop executions as total. Of course this situation is understandable for a construction management which is struggling with time and at many sides. However, it is expected that all HAZID workshop executions are well documented step by step and with all details including all assumptions made, the bases of values used in estimations, considerations being taken into account in assessments, even the results of participations or

consultations with workforce etc. as it is don in the comprehensively detailed risk registers. It is clear that studies are progressing in the direction of more accurate and comprehensive quantitative estimation of risks and evaluable preventive control measures. For instance, people wants to determine which safety program element application results which amount of reduction in risk estimation. Nevertheless, for the time being, it should be accepted as a reality that the assessments for risk and selection of safety program elements are mostly based on the professionals' initiatives and intuitions in construction industry, but on the other hand it should be also noted that a complete documentation is the general commitment of all competent people as the requirement of a successful OH&S management system implementation.

The results and conclusions of the case study related with hazard identification, risk assessment and determining controls are, in fact, presented in "risk registers" tables comprehensively. In this respect, for cut and cover underground stations construction, the tables of risk registers for Üsküdar Station Construction and for tunnel construction, the tables of risk registers for EPB TBM tunnels (Yedikule Construction Site) are presented in the case study.

For a short outline, it is found that the hazards identified in the case study for cut and cover underground stations construction do not include any further items than the ones which are determined in literature for health and safety aspect in general. These hazards are "demolition", "earthworks", "construction equipment", "electrical works", "mechanical works", "lifting", "work at height", "hot work", "cold work", "tools", "compressed air", "manual handling", "road traffic" due to activities (accidents), and additionally "security", "owner employee/subcontractors", "equipment/tools/material supplied", "operations", "special operations", "emergency situations", "flood", "fire" and "collapse" as source and situations for safety aspect; while "mental and physical insufficiency of employee" and "noise" for health aspect. It is noted that in the case study, for mitigation, generally; procedures, method of statements, instructions, technical specifications etc. which all are administrative control measures of an OH&S management system are predicted besides the detailed proposed preventive actions. It is thought that, the use of administrative control measures in such a level for mitigation is the measure of how robust the commitment of top management on OH&S policy is. It is also noted that all risk levels (rating) are anticipated to reduce to the value of 4, which corresponds to acceptable risk class, after mitigation for all types of hazards.

It is found that the hazards identification, risk assessment and determining controls processes in the case study for tunnel construction are very comprehensive and specific. For tunneling works, items specifically considered in hazard identification, risk assessment and determining control processes can be noted as tunneling boring and erection works which is studied under “accidents in tunneling” topic; tunneling “alignment conflicts”, tunneling ground stability which is studied under “tunneling incidents” topic, “structural hazards at shaft”, “tunnel installations” and “maintenance”. Besides these, it can be added to the items considered in hazard identification, risk assessment and determining control processes, the general construction works which is studied under “construction-accidents” topic and “fire”, ”flood”, “earthquake” situations. In the following, some major hazards identified in the case study for tunnel works are tried to be outline without falling in repetitions. Hazards under topic of “accidents in tunneling” are determined as “confined space”, “TBM”, “belt conveyor”, “segment erection”, “tunnel transport”, “toxic gases”, “explosive gases” and “chemicals”. Under the topic of “alignment conflict” hazards identified for tunnel works as top events are “deviation from alignment”, “instability tunnel”, “very high settlements, blow out, tunnel face instability”, “damage to deep foundations” and “problems during tunneling”. “Tunneling incidents” related with ground stability, hazards as top events are “face instability, high surface settlements”, “heave of ground, uplift, blow out”, “ground swelling”, “side wall collapse of twin tunnels”, “failure of segment lining”, “collapse of tunnel”, “uncontrolled water inflow into the cutter head chamber” and “segment floating”. “Structural hazards at shaft” are identified as top events “failure at the foundation of shaft”, “failure at foundation of side walls”, “failure of piles”, “failure of support system (pre-stressed anchors)” and ”collapse of shaft”. Under the topic of “tunnel installations” major hazards as top events are registered as “electrical installation out of order”, “lighting system out of order”, “water supply system out of order”, “ventilation system out of order”, “communication system out of order”, “fire fighting installations missing” and “first aid installations missing”. For the general construction works which is studied under “construction-accidents” topic hazards identified in additions to the ones determined for cut and cover underground stations construction can be noted as “running trains”, “overhead HV power lines”, “false currents” and “pipe/pump/stationery plant”. It is possible to see all details related with “maintenance”, “fire”, “flood” and ”earthquake” items, and again root cause analysis, risks assessments, mitigation measures and proposed actions for each hazard identified in risk registers, so they are not needed to repeat here.

However, it is noted in the case study for tunnel construction that “health” aspect is not documented as it is done for “safety” aspect which is summarized above. For this lack of information related with “health” hazards, it is advised to refer BS 6164:2001 and anyhow “health” hazards are also given at “Table 4.8 Principal occupational health hazards” in the thesis.

The current investigations try to clarify the influence of design of project on construction accidents. It is accepted that participants in construction industry are segregated even regarding design and construction stages. This situation complicates communications and obscures responsibilities of parties and so the success of OH&S is very much affected from this conflict. For this reason, today, there is consistent movement towards to an integrated work approach especially for design and construction lags of construction projects. In this respect, it should be noted that a good example of the integrated work approach mentioned above is applied in the case study. In fact, in the case study the contract of the work covers “design” and ”construction” items together and so GN organization is responsible for both design and construction phases of the project. It is thought that this types of contracts provide positive effects on the establishment of a successful OH&S management systems and reducing the construction accidents.

As it is noted, the increase of using subcontractors in construction industry has been affecting the success of OH&S management systems in negative order. So current investigations intensified on the subcontracting system in construction in meaning of its effects on safety climate in the workplace and the implementation of OH&S management system. In this respect, it is thought that in the case study subcontractors are well organized and participated regarding the safety management of the workplace. The best example of this situation is related with the “job specific risk assessment and mitigation plans (RAMPs)”. In fact in the case study, for each job performed by subcontractors together with the method statements a job specific RAMP is prepared before the start of the work. This is asked directly from subcontractors but if needed, they are also assisted by GN organization. It is thought that this way of working helps very much to provide high participation of subcontractors to safety management and at the same time to constitute a good safety climate between subcontractors employees and hence in overall workplace.

It should be noted that in the case study, the Project Manager of GN organization is the one building overall the OH&S management system in the workplace. So he is the one who is very much aware of importance of OH&S management system for the project and he is a competent in this respect. It is possible to see good effects of this situation in implementation of OH&S management system and in providing a better safety climate in the case study. It is thought that this is a good example of that the awareness of top management and their competency in OH&S aspects has crucial importance in the respect of positive effects in establishing and implementation of an effective management system and providing high level safety climate in a workplace.

Further studies as a case study and as the complementary of this thesis for implementation, performance measurements and assessment of near miss occurrences in the Marmaray Project seem to be valuable.

It is thought that further studies planned at different construction sites for cut and cover underground stations and tunnel construction would be valuable for having the chance of comparing the results of variant applications in the construction industry.

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