風險評估與管理 – 捷運建設的經驗

Risk Assessment and Management

- Lessons Learnt in Metro Projects

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BSc MSc PhD PE FICE

13 Nov 20

35年捷運建設: 1986 - 2020

- 可行性研究, 規劃, 基本設計, 細部設計, 施工, 整合測試, 通車履勘
- 業主, 設計顧問, 監督顧問, 土建營造廠商, 機電系統廠商
- 傳統設計後施工, Design-Build, Turnkey, BOT

>150 km Metro Projects

- MRT, MCT, LRT, 傳統客運/貨運鐵路
- 用地取得, 聯合開發
- 獨立驗證與認證

  Independent Verification & Validation, IV&V
- 價值工程 Value Engineering, VE
- 風險管理 Risk Management

綱要 Outlines

1. 投入風險管理領域之由來 What to attract attention?
2. 風險管理作業 Risk management process
3. 風險管理案例 Cases – Planning/Design, Construction
4. 國際風險管理標準 International standards

Major Accidental Events in Taiwan and Overseas

1994(April)	TRTS-CH221: Excessive ground subsidence during segment replacement in the interface of bored tunnel and vent shaft
1994 (Oct)	Heathrow Express Rail Link: Collapse of a NATM tunnel
1994(Nov)	TRTS-CN252: Ground loss induced by piping in deep excavation of an underground station
1995(April)	TRTS-CN261: Ground loss during TBM-launching
1995(July)	TRTS-CN262: Excessive ground loss during TBM-docking
	TANEEB Suei-shan Tunnel : Series of accident during TBM & NATM tunnelling
2002(Aug,Nov)	THSRC-Hu-ko Tunnel: Ground loss during NATM tunnelling
2003(Feb)	TRTS-CD266: Ground loss during TBM-docking
2003(May)	KRTC-LUO04: Excessive ground loss during TBM-docking

2003(July) Shanghai Metro 4: Tunnel collapse during the excavation of a cross-passage

2003(Aug) KRTC-O01: Ground loss induced by piping due to defective diaphram wall during the excavation of an underground station

2003(Aug) TRTS-CK570C: Flooding due to a gap btwn the river bank and a pump station

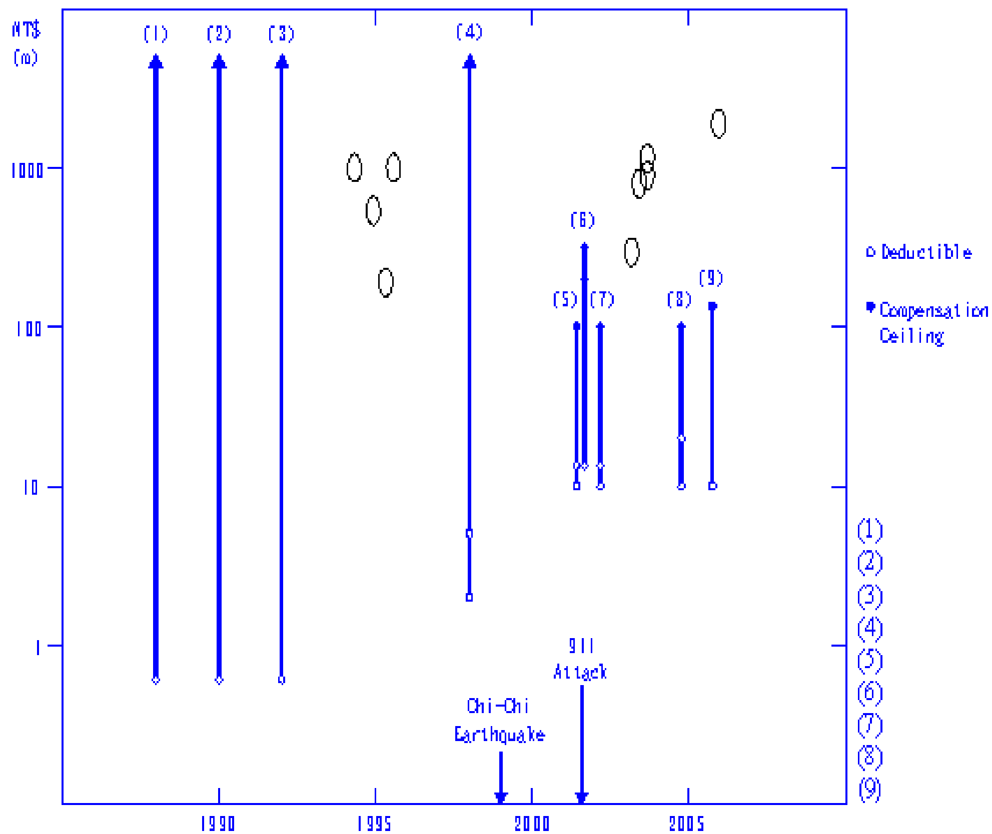
2004(April) Singapore LTA-MRT Circle Line: Collapse of 33m deep excavation of a cut-and-cover tunnel

2005 (Dec) KRTC-LUO09: Excessive ground subsidence during the excavation of a sump inside a cross-passage

2007(Jan) Sao Paulo Metro-Linea 4: Collapse of a NATM tunnel

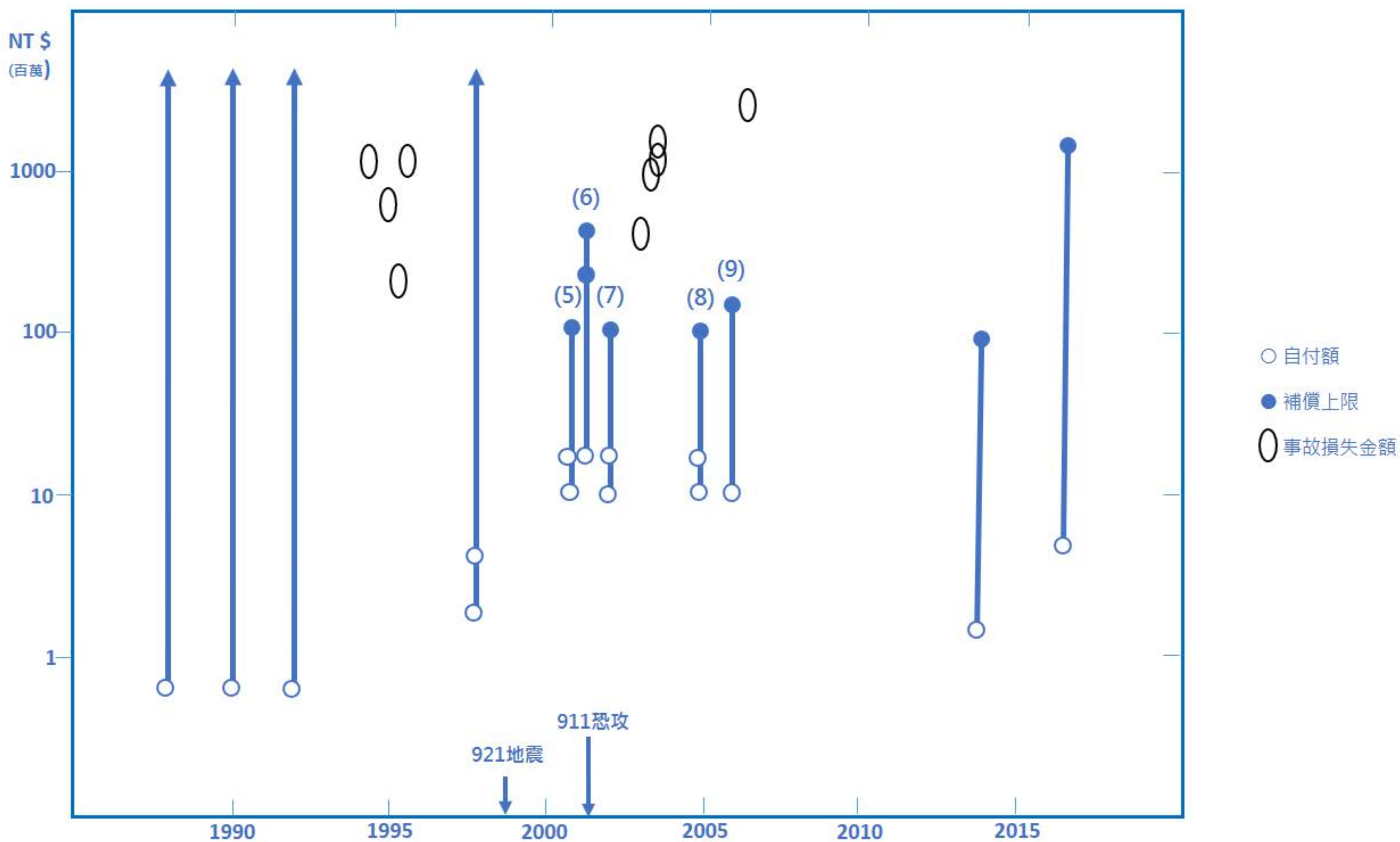
2008(Nov) Hanzho Metro – Line 1: Collapse of 16 m deep excavation

Contractors All Risks Insurance & Third Party Liability Insurance of Underground Works (Chuay,2008)



- KL-MRT2 (2016)
  - Deductible: NT$7-10m
  - Limit of indemnity: NT$2,200m
- 台北捷運萬大線 (2014)
  - 自負額: NT$2-5m
  - 賠償上限: 單一事故NT$100m
    (區段標上限NT$300m)

捷運工程保險和重大施工意外之統計資料

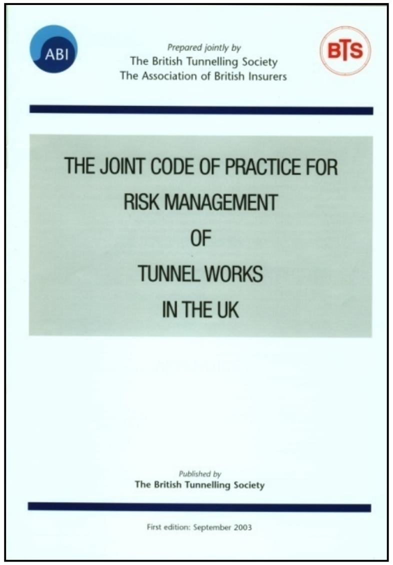


Problems :

- Nightmare for clients or contractors
    - No offer of insurance policy by insurers
    - High premium but very limited coverage (low frequency but severe consequence)
- Concerns by insurers
    - Frequency of accidents
    - Severe consequence

Joint Code of Practice for Risk Management of Tunnel Works in the UK

- Discussion at ICE, London in July, 2002 about the "JCoP for the procurement, Design and Construction of Tunnels and Underground Structures in the United Kingdom"
- Jointly produced by Association of British Insurers and British Tunnelling Society in 2003
- Pre-requisite for insurance



ITA (Intern'l Tunnelling Association) Working Group 2 (2004):

Guidelines for tunnelling risk management

ITIG (Intern'l Tunnelling Insurance Group) (2006):

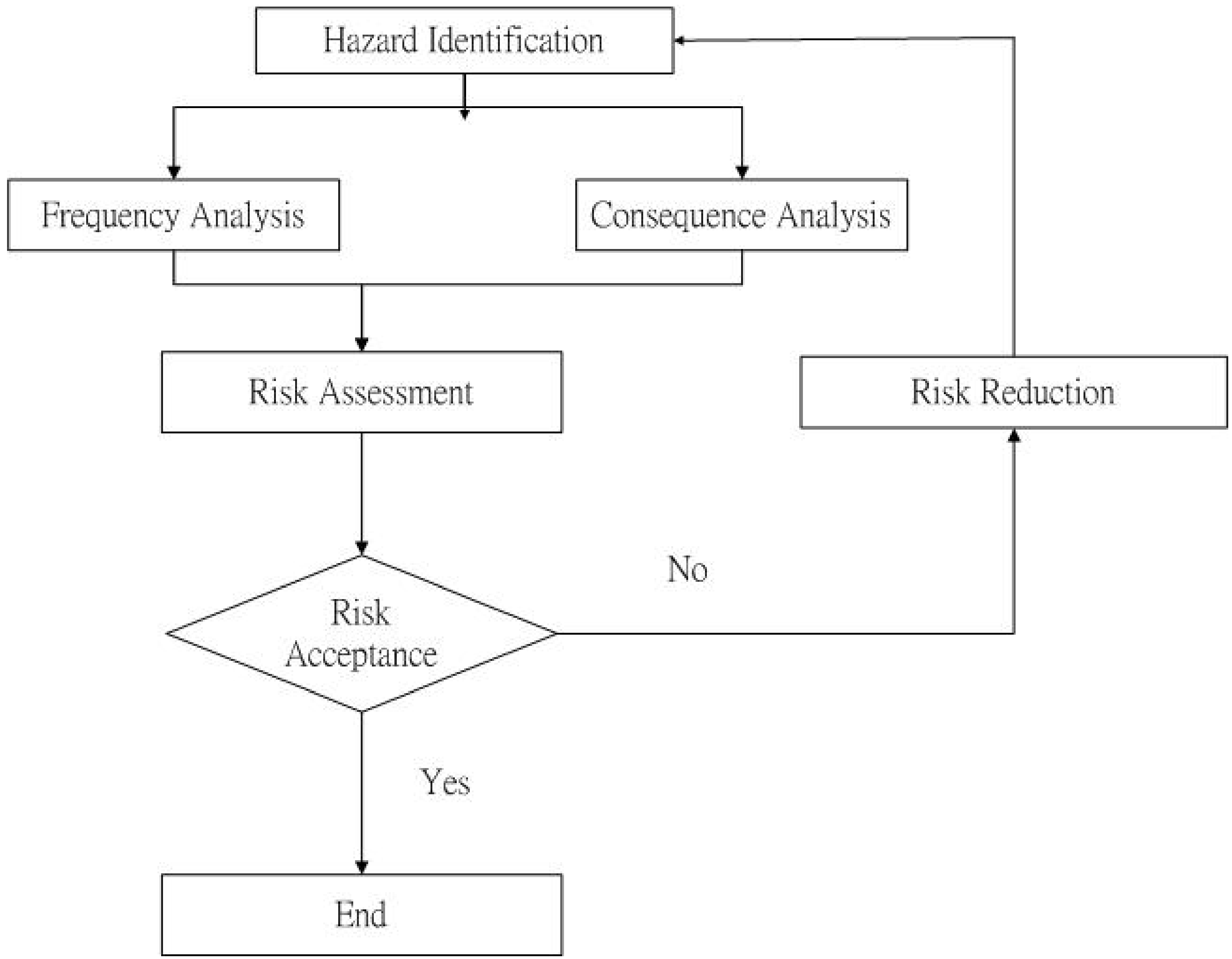
A Code of Practice for Risk Management of Tunnel Works

- Supported by ITA and Intern'l Association of Engineering Insurers

風險定義

- 生命, 財務, 時間, 政治
- 施工, 營運
- 規劃, 設計, 施工階段

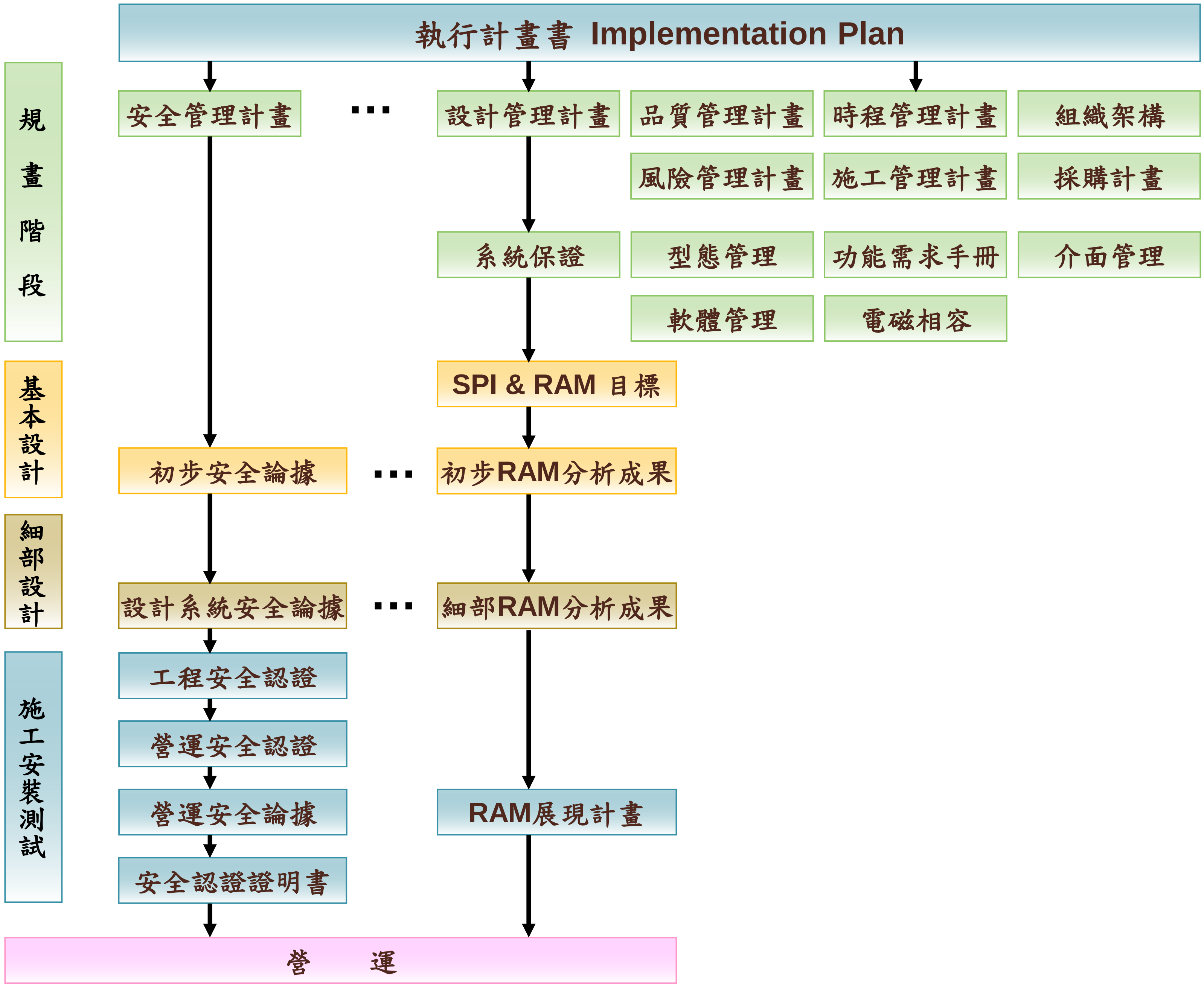
The Risk Assessment Process



Risk Level Matrix

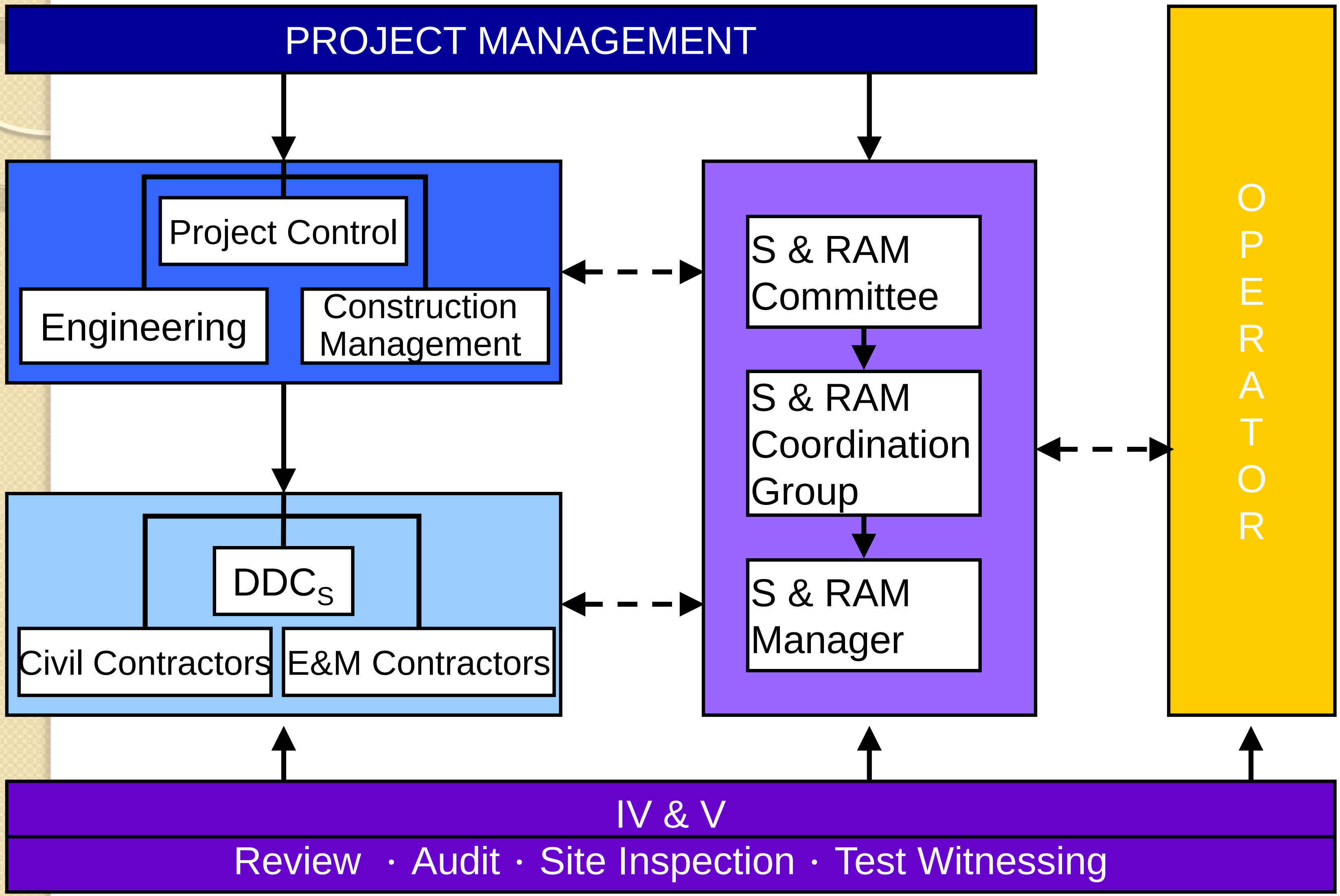
★ Frequency of occurrence of a hazardous event	Risk Levels			
Frequent	Undesirable	Intolerable	Intolerable	Intolerable
Probable	Tolerable	Undesirable	Intolerable	Intolerable
Occasional	Tolerable	Undesirable	Undesirable	Intolerable
Remote	Negligible	Tolerable	Undesirable	Undesirable
Improbable	Negligible	Negligible	Tolerable	Tolerable
incredible	Negligible	Negligible	Negligible	Negligible
	Insignificant	Marginal	Critical	Catastrophic
	Severity Levels of Hazard Consequence			

計畫管理文件架構



執行計畫書 Implementation Plan
規畫階段
基本設計
細部設計
施工安裝測試
安全管理計畫
設計管理計畫
品質管理計畫
時程管理計畫
組織架構
風險管理計畫
施工管理計畫
採購計畫
系統保證
型態管理
功能需求手冊
介面管理
軟體管理
電磁相容
SPI & RAM 目標
初步安全論據
初步RAM分析成果
設計系統安全論據
細部RAM分析成果
工程安全認證
營運安全認證
營運安全論據
RAM展現計畫
安全認證證明書
營 運

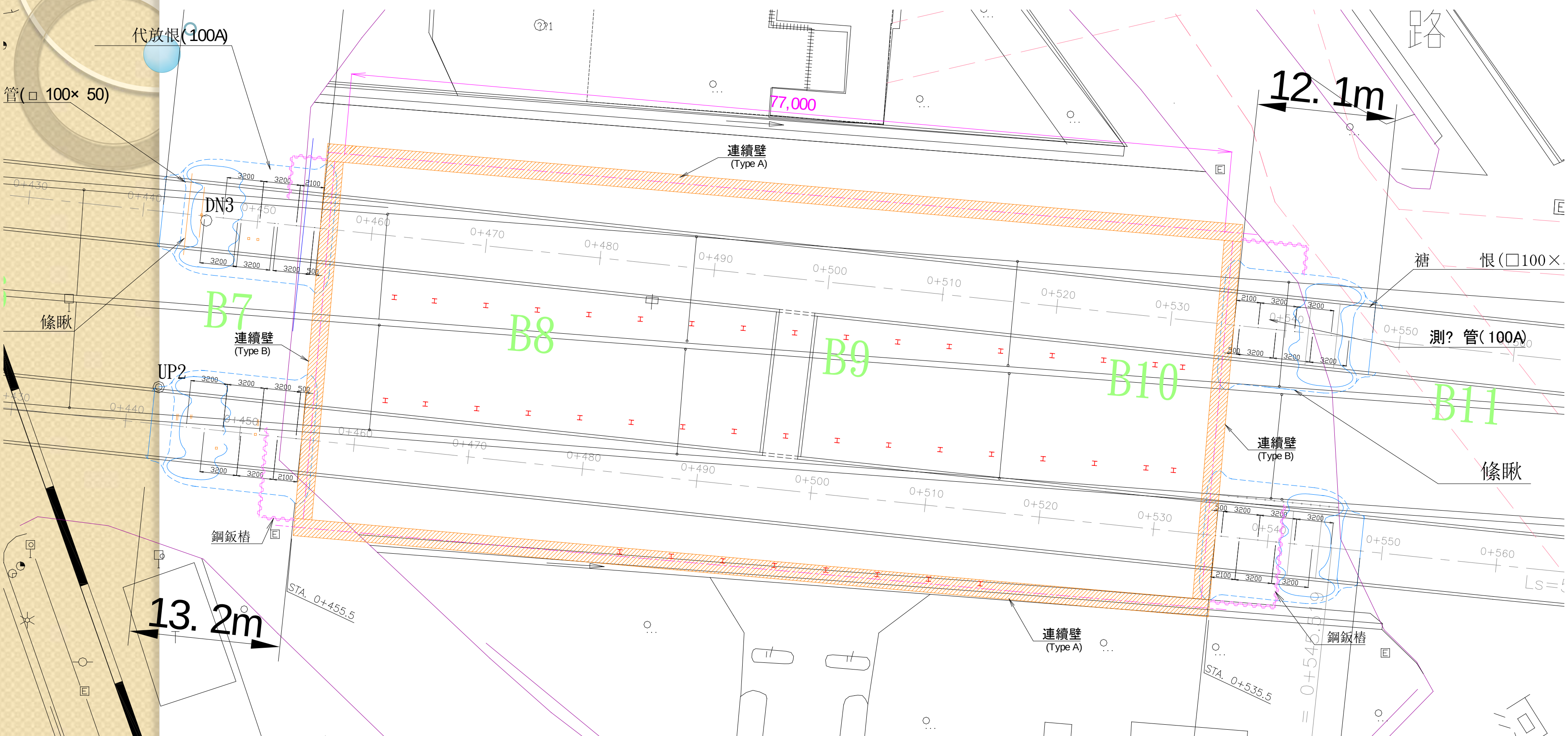
Project Organisational Structure



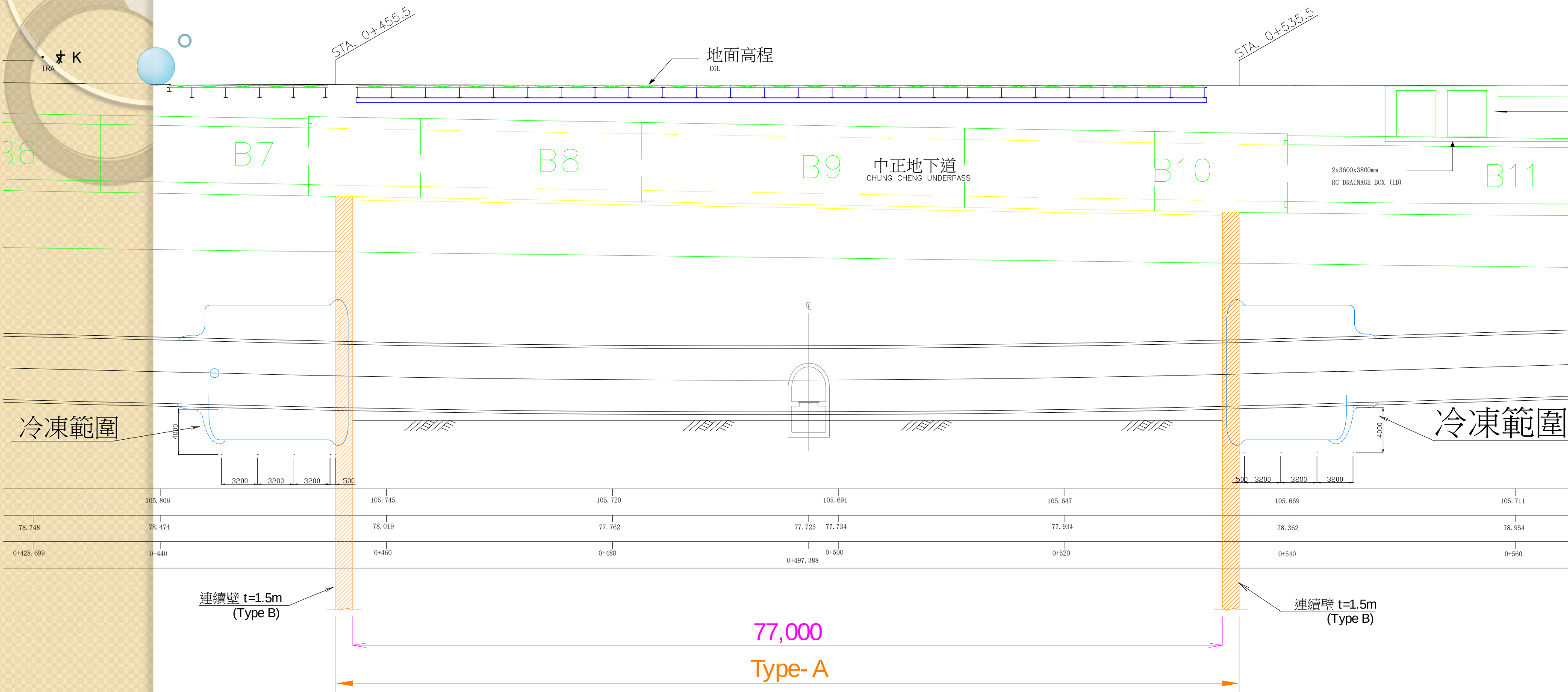
Case History I

- Kaohsiung MRT R&O Lines LUO09 Recovery Plan

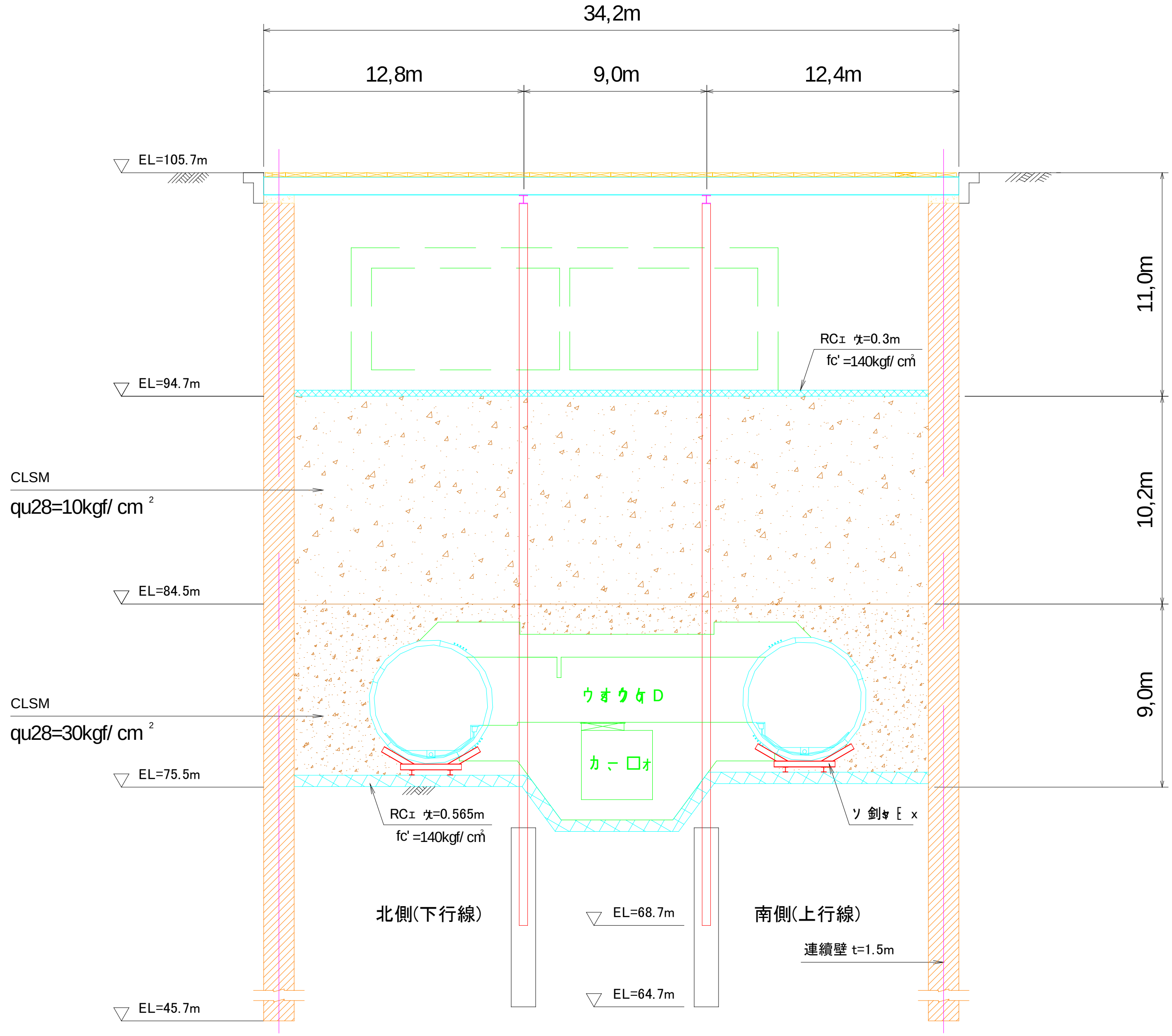
LUO09 Recovery Plan



LUO09 Recovery Plan



LUO09 Recovery Plan



風險疊加

- 細沙或沉泥/地下水位高
- 設計變更: 二個聯絡通道位於地下道二端, 變更為一個位於地下道中央
- 深度增加
- 聯絡通道上方地下道成為土壤改良作業的障礙
- 集水井設於聯絡通道內

Case History 2: Planning/Design Stage

Necessity of cross-passages in bored tunnels

Prescriptive criteria vs Performance-based approach

- NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems (2007)

  < 6.2.2.3 Means of egress (Cross-passageways): Not farther than 244 m (800 ft) apart

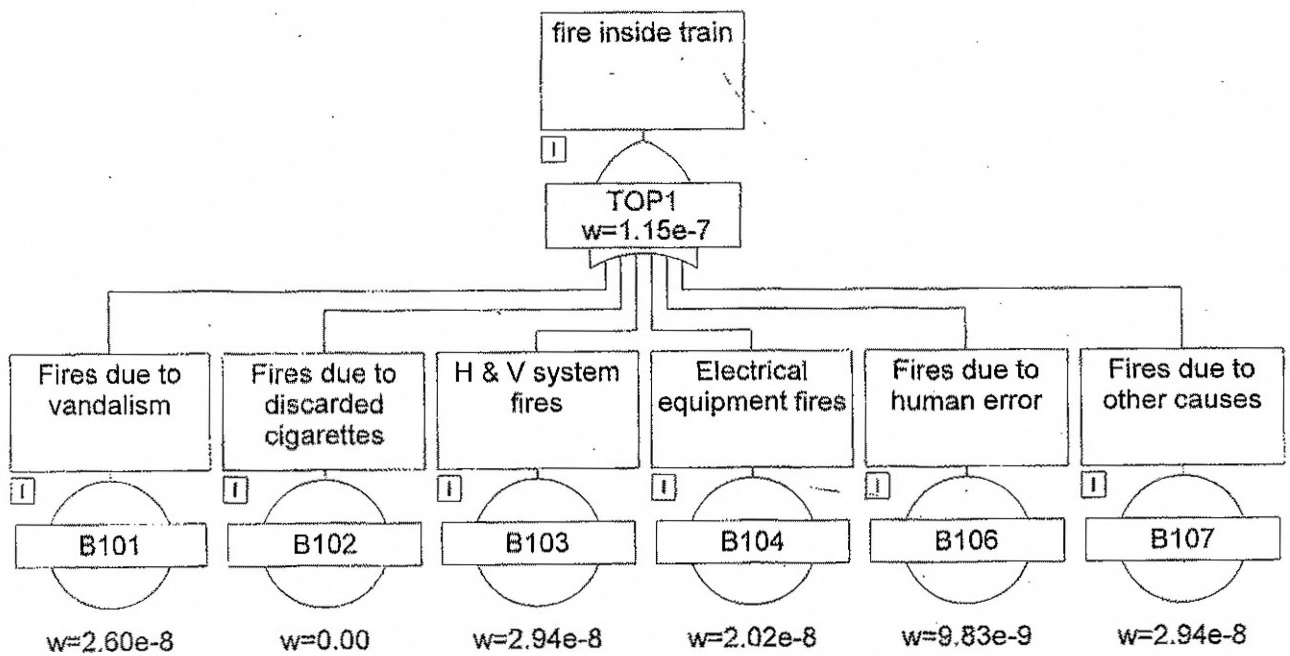
  < 1.4 Equivalency: New method, material or device equivalent to or superior to the requirements of this standard with respect to fire and life safety

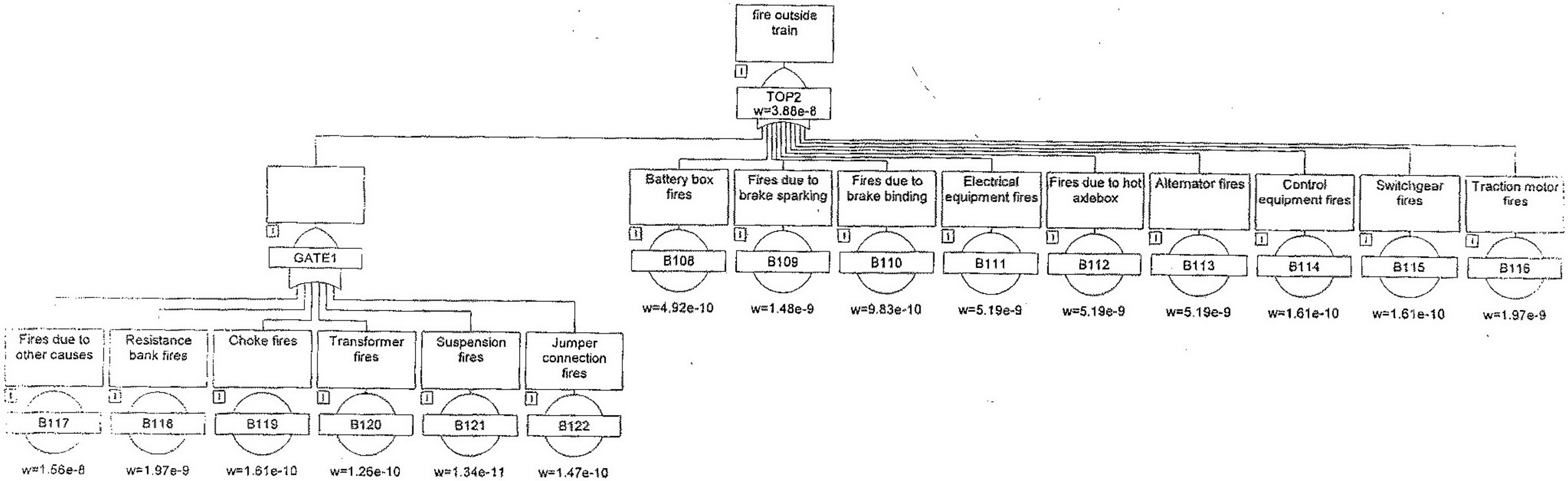
  < 4.2.2 Goal: Minimum requirements for those instances where "noncombustible materials are not used"

- 定量風險評估
  Quantitative Risk Assessment, QRA

Fault Tree Analysis, FTA 災害樹分析

- Data base from UK EMU operation of 34 years
- Data from KCRC EMU operation of 14 years
- Internal fire event: 20 month return period
- External fire event: 15 month return period


fire inside train
TOP1
w=1.15e-7
Fires due to vandalism
Fires due to discarded cigarettes
H & V system fires
Electrical equipment fires
Fires due to human error
Fires due to other causes
B101
B102
B103
B104
B106
B107
w=2.60e-8
w=0.00
w=2.94e-8
w=2.02e-8
w=9.83e-9
w=2.94e-8



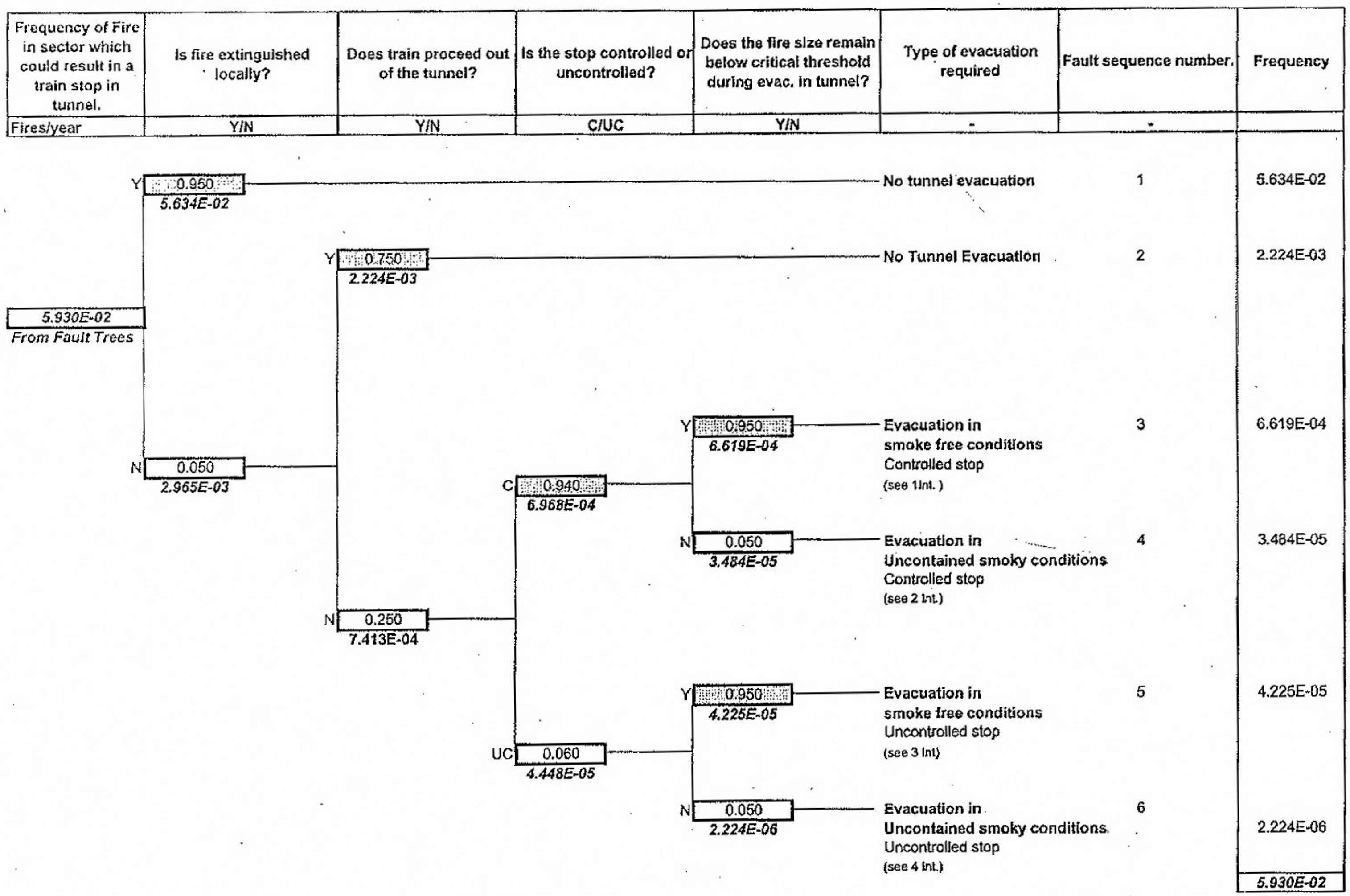
fire outside train
TOP2
w=3.88e-8
GATE1
Fires due to other causes
B117
w=1.56e-8
Resistance bank fires
B118
w=1.97e-9
Choke fires
B119
w=1.61e-10
Transformer fires
B120
w=1.26e-10
Suspension fires
B121
w=1.34e-11
Jumper connection fires
B122
w=1.47e-10
Battery box fires
B108
w=4.92e-10
Fires due to brake sparking
B109
w=1.48e-9
Fires due to brake binding
B110
w=9.83e-10
Electrical equipment fires
B111
w=5.19e-9
Fires due to hot axlebox
B112
w=5.19e-9
Alternator fires
B113
w=5.19e-9
Control equipment fires
B114
w=1.61e-10
Switchgear fires
B115
w=1.61e-10
Traction motor fires
B116
w=1.97e-9

Event Tree Analysis, ETA

事件樹分析

Event Trees

<u>Fire in Passenger Carriage In Single Track Tunnel (Internal Fires)</u>

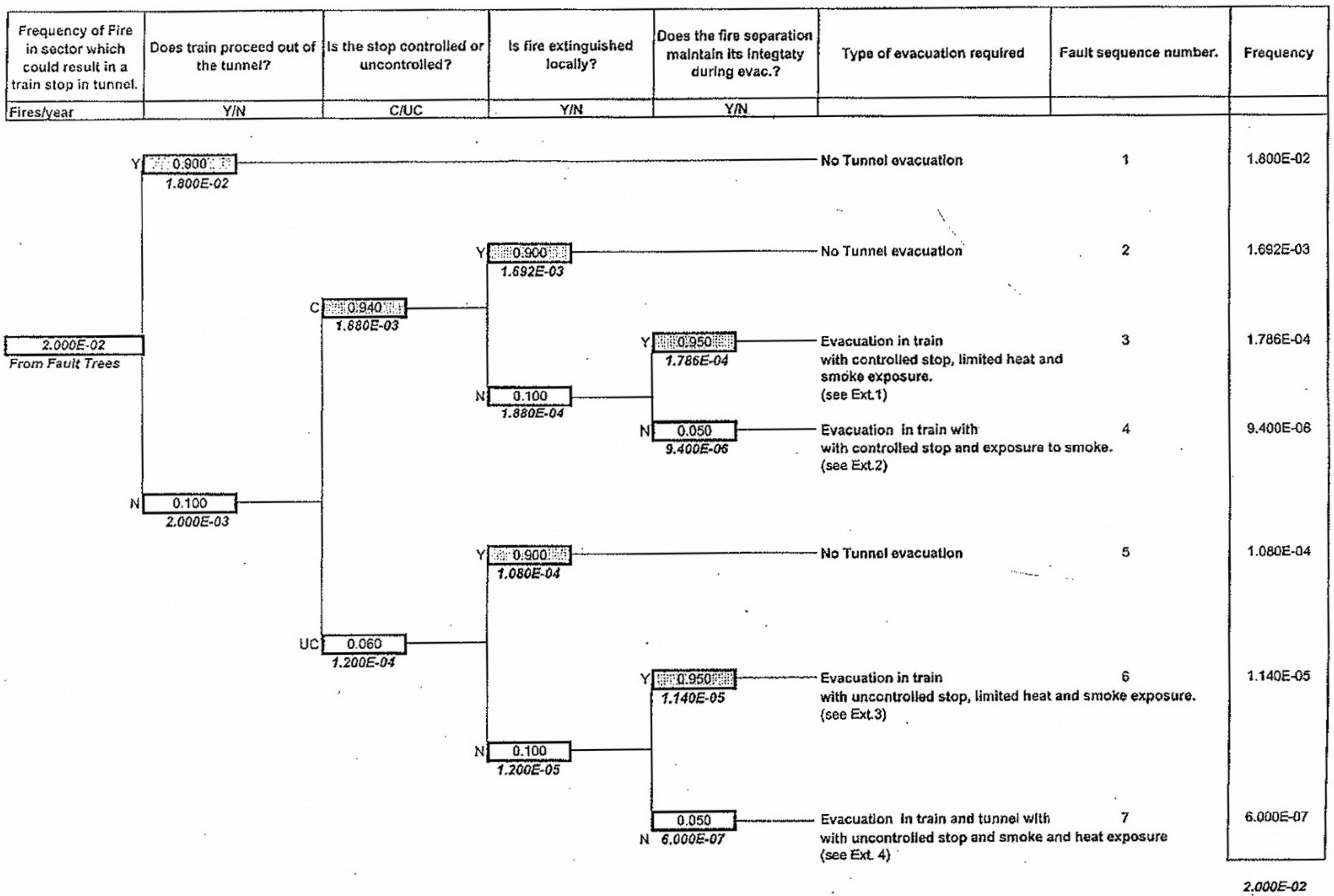


2 Int - Evacuation in Tunnel with uncontained smoke and controlled Stop

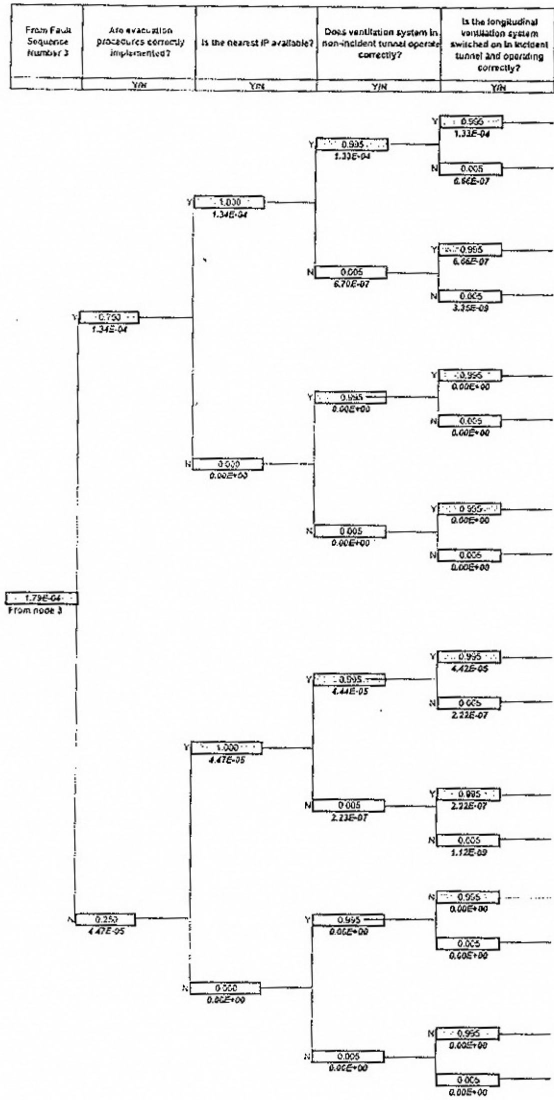
Fully Loaded Trains (frequencies, consequences, risks)

From Fault Sequence Number 4	Are evacuation procedures correctly implemented?	Can passengers exit through nearest intervention point?	Does ventilation system in non-incident tunnel operate correctly?	Is the longitudinal ventilation system switched on in incident tunnel and operated correctly?	Frequency (ev./yr)	Consequence (N. of people affected)	Risk /yr: Minor Injury	Risk /yr: Major Injury	Risk /yr: Eq. Injury	Eq. Injuries	< 10 Eq. Injuries	10 - 100 Eq. Injuries	100 - 1000 Eq. Injuries
	Y/N	Y/N	Y/N	Y/N	fraction of FLT 0.02						10	100	1000
3.48E-05 From nodes 4	Y 0.750 (2.61E-05)	Y 1.000 (2.61E-05)	Y 0.995 (2.60E-05)	Y 0.995 (2.59E-05)	5.42E-07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0			
				N 0.005 (1.30E-07)	2.72E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0			
			N 0.005 (1.31E-07)	Y 0.995 (1.30E-07)	2.72E-09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0			
				N 0.005 (6.53E-10)	1.37E-11	2.70E+01	2.22E-10	9.23E-11	6.30E-11	5	6.30E-11		
		N 0.000 (0.00E+00)	Y 0.995 (0.00E+00)	Y 0.995 (0.00E+00)	0.00E+00	1.00E+01	0.00E+00	0.00E+00	0.00E+00	2	0.00E+00		
				N 0.005 (0.00E+00)	0.00E+00	1.80E+01	0.00E+00	0.00E+00	0.00E+00	3	0.00E+00		
			N 0.005 (0.00E+00)	Y 0.995 (0.00E+00)	0.00E+00	1.50E+01	0.00E+00	0.00E+00	0.00E+00	3	0.00E+00		
				N 0.005 (0.00E+00)	0.00E+00	2.70E+01	0.00E+00	0.00E+00	0.00E+00	5	0.00E+00		
	N 0.25 (8.71E-06)	Y 1.000 (8.71E-06)	Y 0.995 (8.67E-06)	Y 0.995 (8.62E-06)	1.81E-07	1.50E+01	1.62E-06	6.77E-07	4.62E-07	3	4.62E-07		
				N 0.005 (4.33E-08)	9.07E-10	2.70E+01	1.47E-08	6.12E-09	4.18E-09	5	4.18E-09		
			N 0.005 (4.35E-08)	Y 0.995 (4.33E-08)	9.07E-10	2.25E+01	1.22E-08	5.10E-09	3.48E-09	4	3.48E-09		
				N 0.005 (2.18E-10)	4.56E-12	4.05E+01	1.11E-10	4.62E-11	3.15E-11	7	3.15E-11		
		N 0.000 (0.00E+00)	Y 0.995 (0.00E+00)	Y 0.995 (0.00E+00)	0.00E+00	1.50E+01	0.00E+00	0.00E+00	0.00E+00	3	0.00E+00		
				N 0.005 (0.00E+00)	0.00E+00	2.70E+01	0.00E+00	0.00E+00	0.00E+00	5	0.00E+00		
			N 0.005 (0.00E+00)	Y 0.995 (0.00E+00)	0.00E+00	2.25E+01	0.00E+00	0.00E+00	0.00E+00	4	0.00E+00		
				N 0.005 (0.00E+00)	0.00E+00	4.05E+01	0.00E+00	0.00E+00	0.00E+00	7	0.00E+00		
					7.29E-07		1.65E-06	6.88E-07	4.69E-07		4.69411E-07	0	0

External fire In Single Track Tunnel

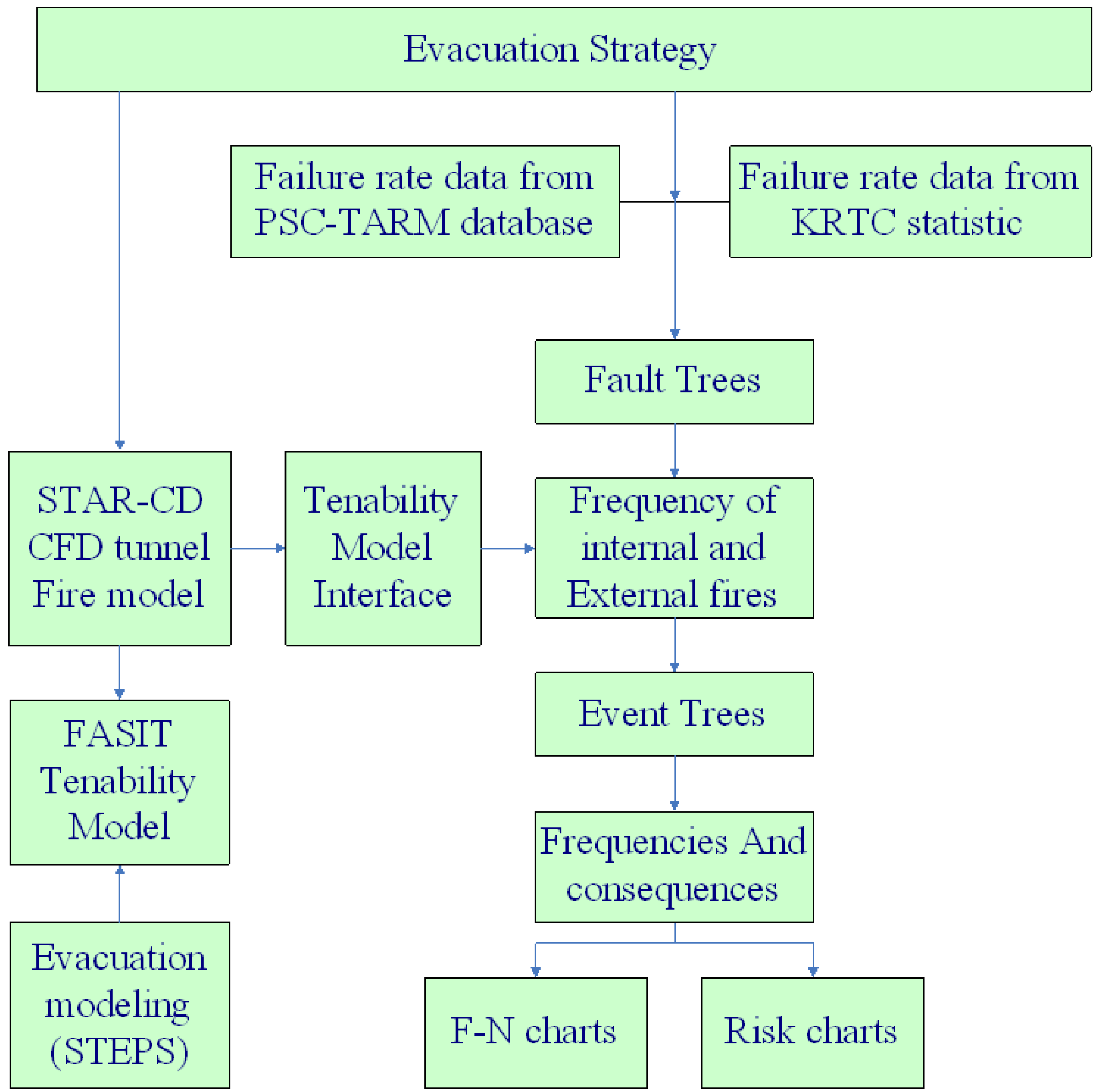


1 Ext - Evacuation for External Fires, Controlled stop, limited smoke & heat exposure.

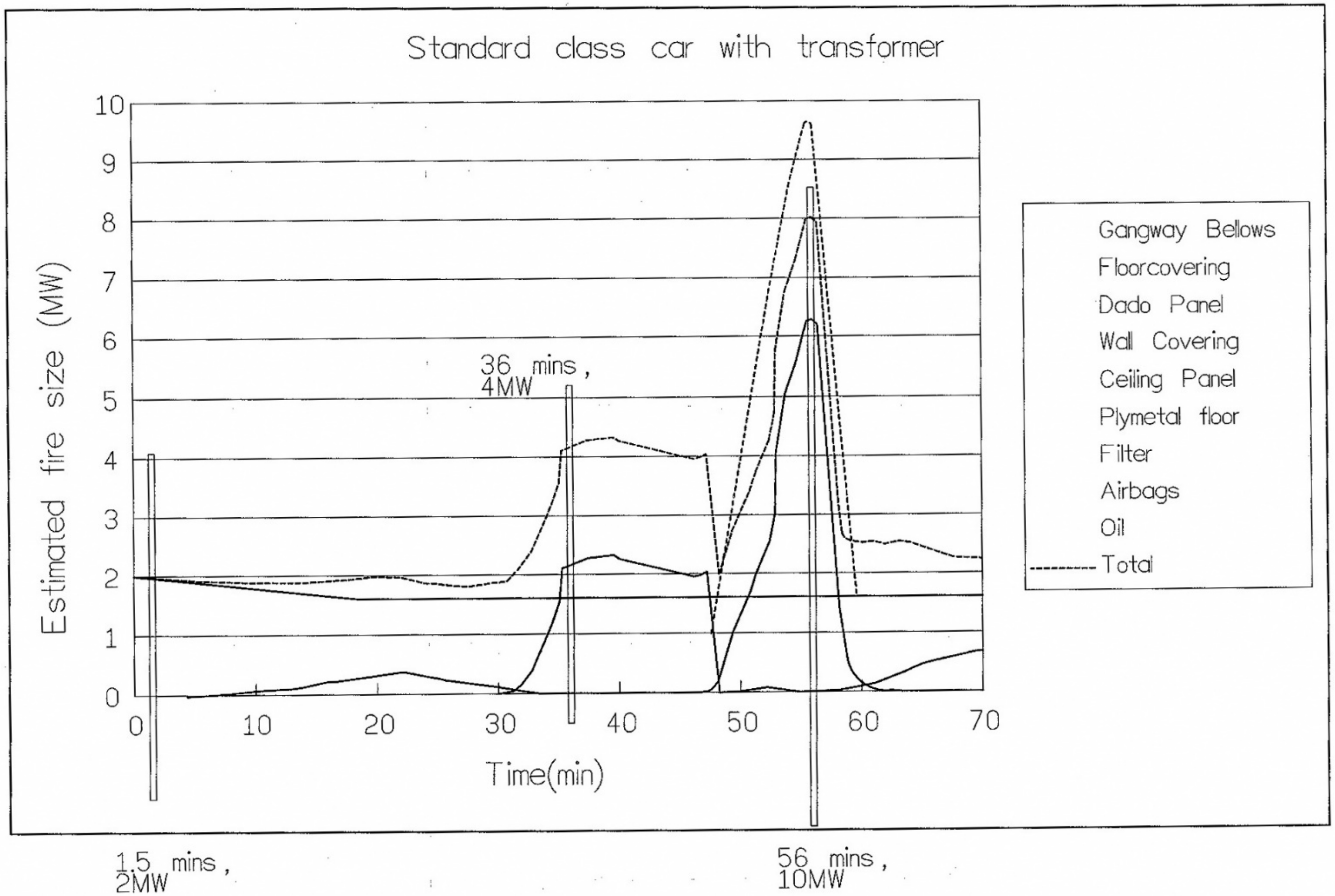


Frequency (ev./yr)	Consequence (N. of people affected)	Risk /yr: Minor Injury	Risk /yr: Major Injury	Risk /yr: Eq. Injury	Eq. Injuries	< 10 Eq. Injuries	10 - 100 Eq. Injuries	100 - 1000 Eq. Injuries
2.78E-06	1.00E+01	1.67E-05	6.64E-06	4.73E-06	2	4.73E-06		
1.40E-08	1.80E+01	1.51E-07	6.20E-08	4.28E-08	3	4.28E-08		
1.40E-08	1.50E+01	1.26E-07	5.23E-08	3.57E-08	3	3.57E-08		
7.01E-11	2.70E+01	1.14E-09	4.73E-10	3.23E-10	5	3.23E-10		
0.00E+00	1.00E+01	0.00E+00	0.00E+00	0.00E+00	2	0.00E+00		
0.00E+00	1.80E+01	0.00E+00	0.00E+00	0.00E+00	3	0.00E+00		
0.00E+00	1.50E+01	0.00E+00	0.00E+00	0.00E+00	3	0.00E+00		
0.00E+00	2.70E+01	0.00E+00	0.00E+00	0.00E+00	5	0.00E+00		
9.25E-07	1.50E+01	8.33E-06	3.47E-06	2.37E-06	3	2.37E-06		
4.65E-08	2.70E+01	7.53E-08	3.14E-08	2.14E-08	5	2.14E-08		
4.65E-09	2.25E+01	6.28E-08	2.62E-08	1.78E-08	4	1.78E-08		
2.34E-11	4.05E+01	5.68E-10	2.37E-10	1.61E-10	7	1.61E-10		
0.00E+00	1.50E+01	0.00E+00	0.00E+00	0.00E+00	3	0.00E+00		
0.00E+00	2.70E+01	0.00E+00	0.00E+00	0.00E+00	5	0.00E+00		
0.00E+00	2.25E+01	0.00E+00	0.00E+00	0.00E+00	4	0.00E+00		
0.00E+00	4.05E+01	0.00E+00	0.00E+00	0.00E+00	7	0.00E+00		
2.09E-02		2.54E-05	1.06E-05	7.22E-06		7.22E-06	0.00E+00	0.00E+00

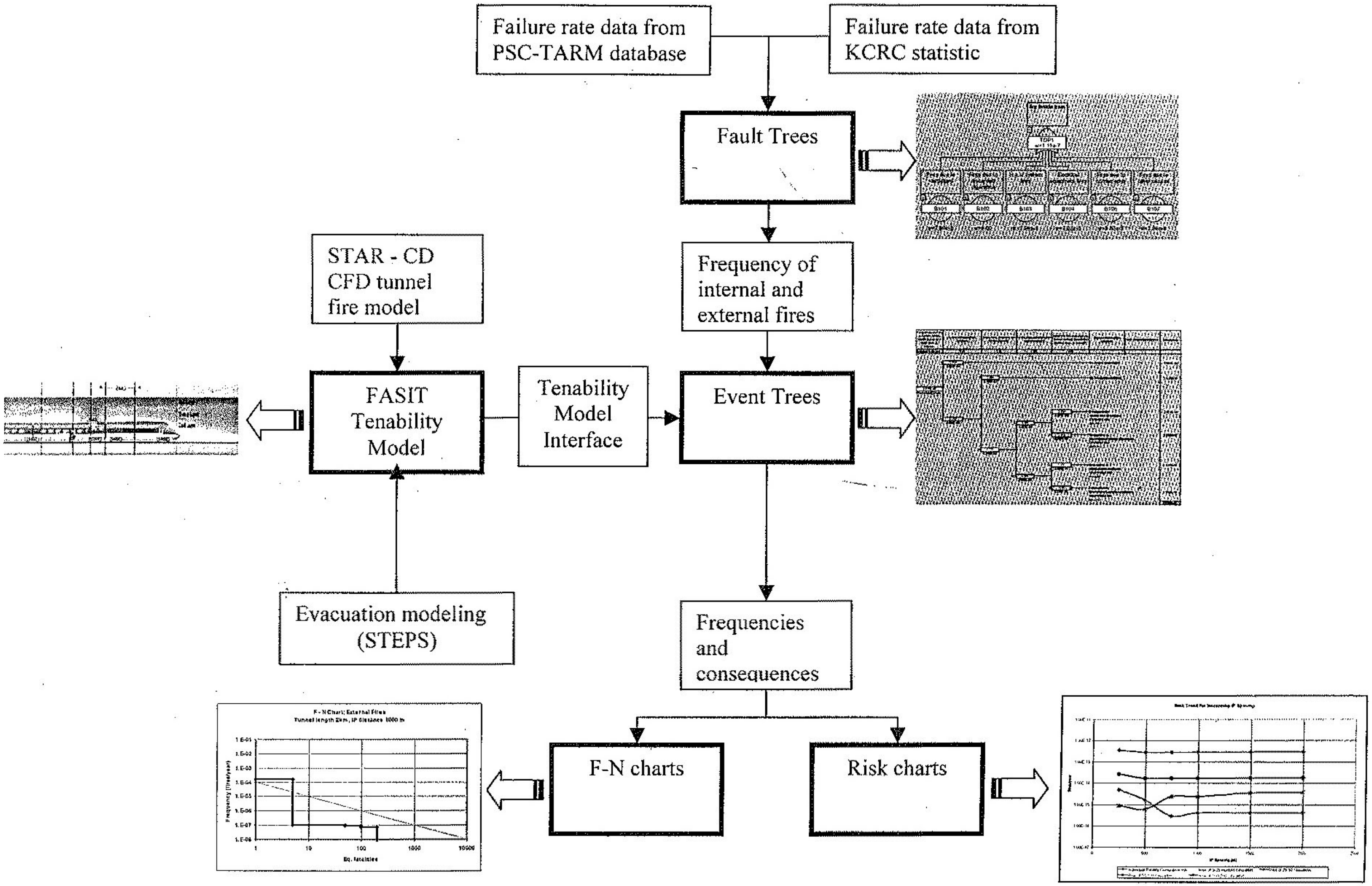
Structure of Tunnel Fire Risk Model



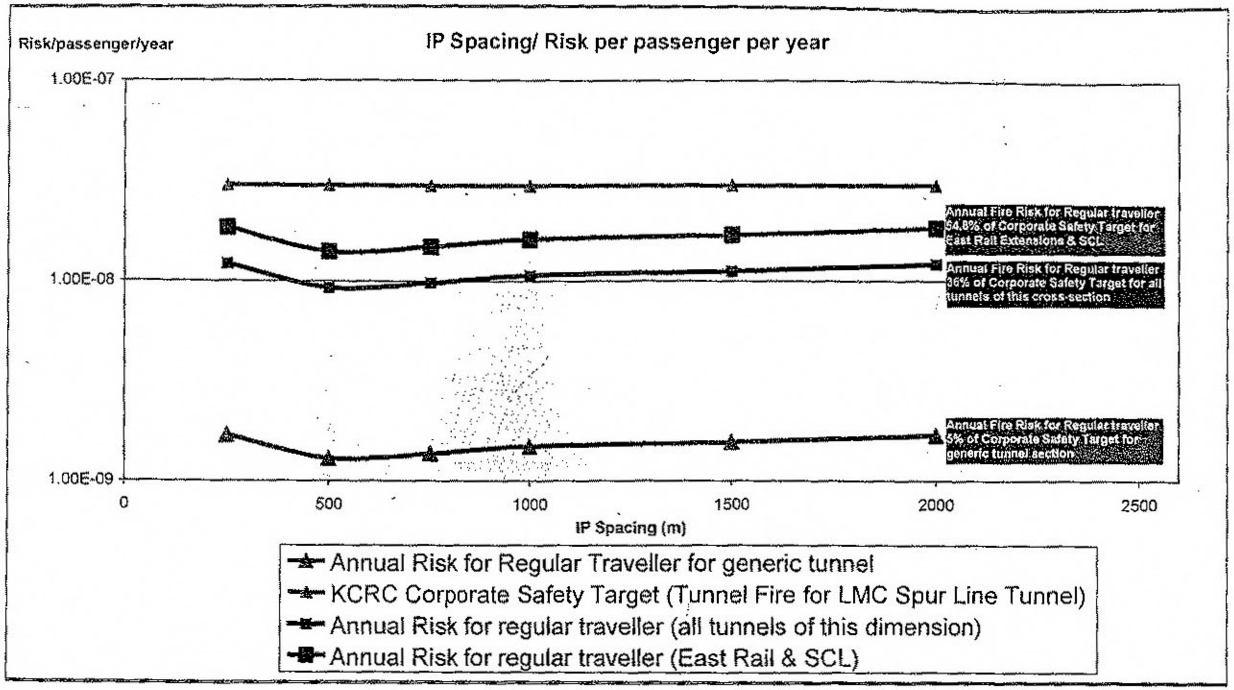
Standard Fire Curve for DFRA and QRA Tunnel Fire Analysis



Structure of KCRC TFRM



Trend Graph for Individual Equivalent Injury Risk



Necessity of cross-passages in bored tunnels (Kowloon Canton Railway 2003)

- Deterministic Fire Risk Assessment of Tunnel fires
    - < Principle: Passengers to walk away in tunnel fire and reach a place of safe passage
    - < Evacuation strategy of passengers in tunnel fire
        - - Transverse vs Linear evacuation routes
            - - Duration of evacuation against various cross-passage spacing
        - - Evacuation through side doors or end doors
    - < Key factors in the safety of evacuation
        - - Evacuation in the correct direction
        - - Correct operation of the ventilation system

Possible Solution: ***Transverse*** vs. ***Linear evacuation***

Necessity of cross-passages in bored tunnels (Kowloon Canton Railway 2003) Results of analyses

- No measurable safety benefit provided by a closely spaced cross-passage configuration
- Vital safety factors: Initiation of evacuation in the correct direction &
  Correct operation of the ventilation system
- Simple procedure for linear evacuation providing better crowd control and reducing the likelihood of accidents

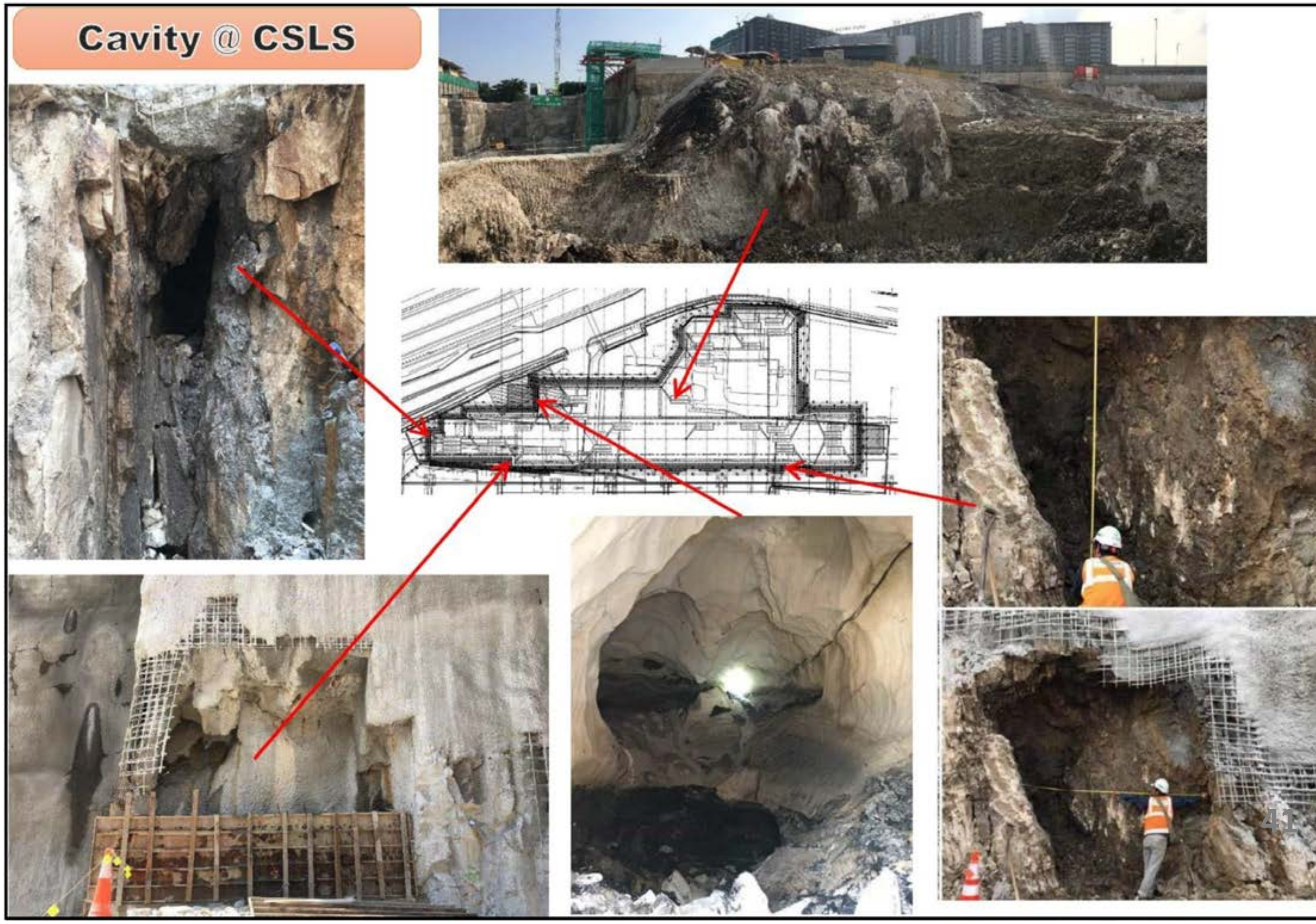
Case History 3

- Kuala Lumpur MRT Line 2

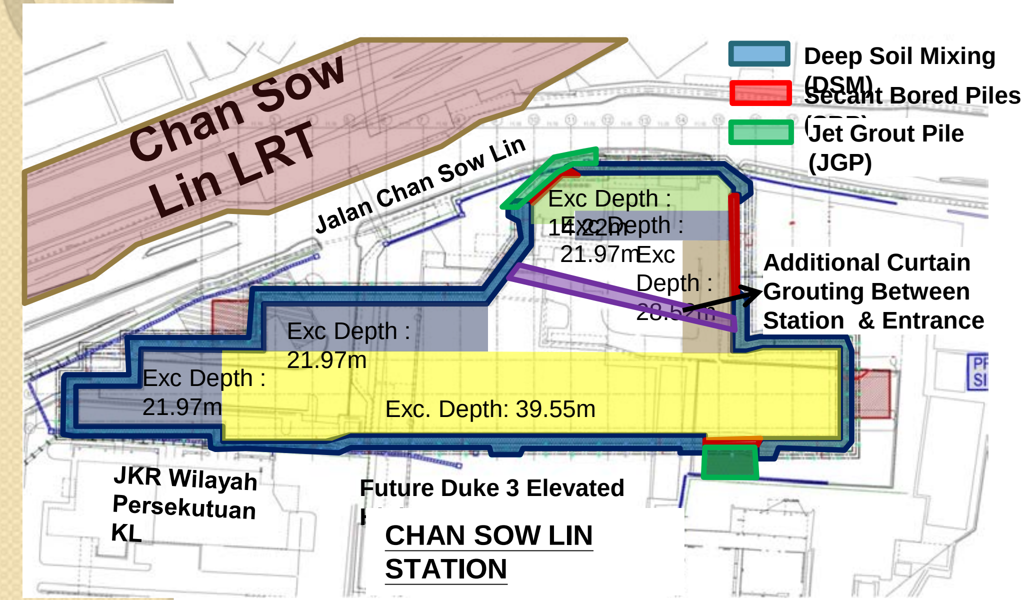
  Chan Sow Lin Station, CSLS

FEATURES ALREADY EXPOSED in Chan Sow Lin excavation.

Multiple caves and cavities were unearthed during excavation. Extreme Karst condition exhibit very variable combination of black organic material infills to highly weathered rock.



Geological Conditions

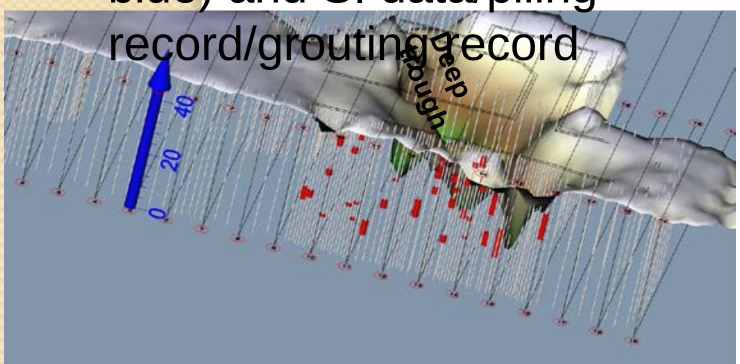


Ground Investigation:

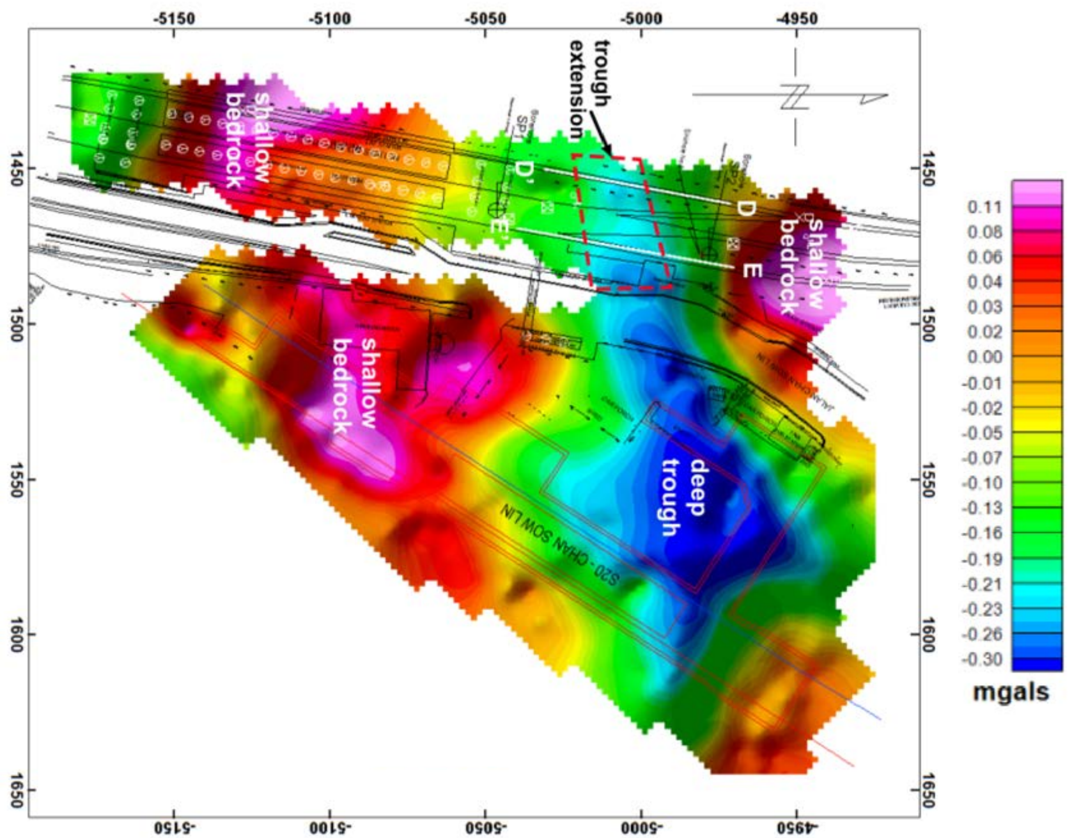
1. Soil Investigation
2. Drilled Holes for Curtain Grouting Surrounding Station Perimeter (2m to 4m spacing c/c)
3. Bored Pile Drilled Hole
4. Microgravity Survey
5. Borehole Televiewer
6. Rock Mapping on Rock Face

Geological Conditions

Deep valley cutting across Chan Sow Lin Station footprint shown by microgravity survey (in blue) and SI data/piling record/grouting record

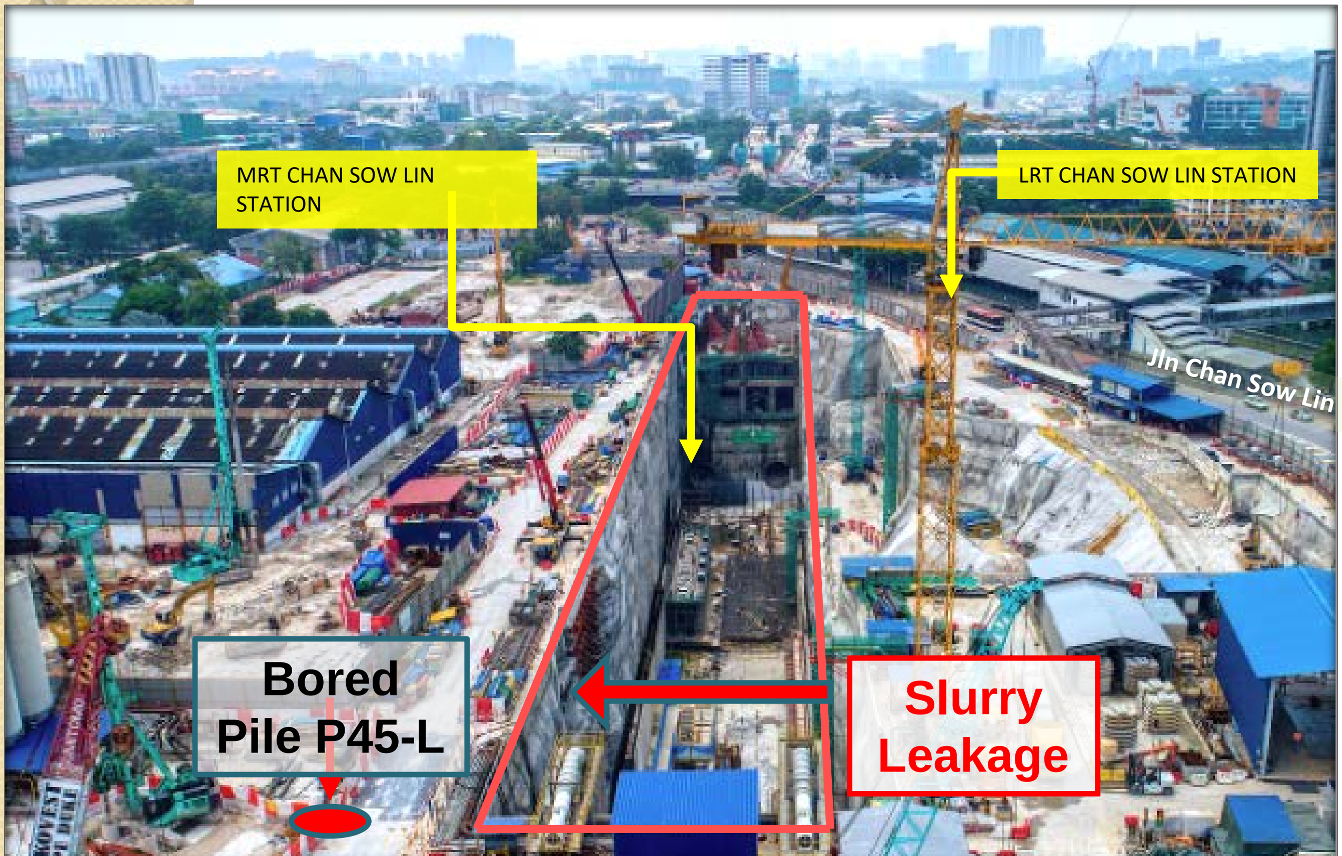


3D VOXLER MODEL



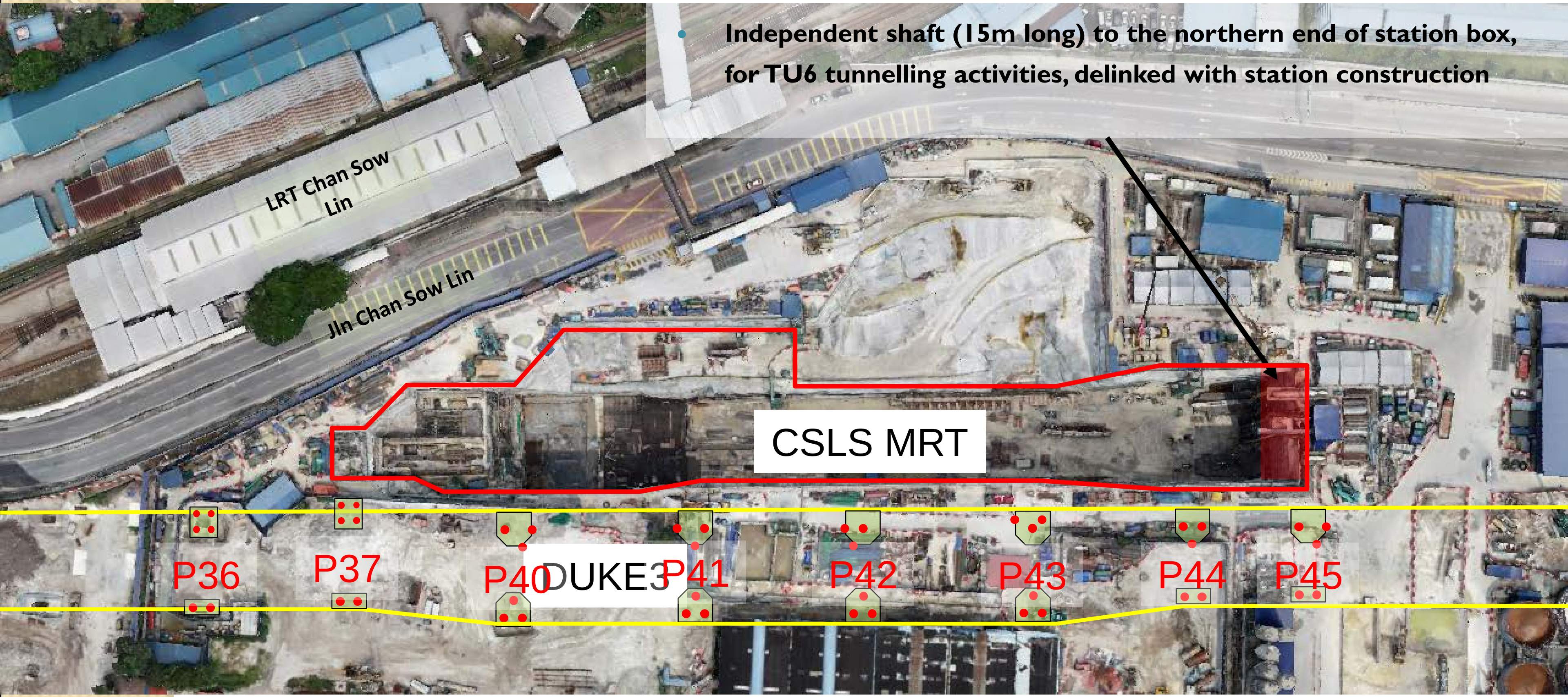
Microgravity Survey & Voxler Rockhead Model

Site Plan



Station Information	
Length	**200 m**
Width	**21.6 m**
Depth	**40 m**
Entrance	**3 nos**
Linkway to LRT	**1 nos**
No. of Floors	**5**

Station Configuration



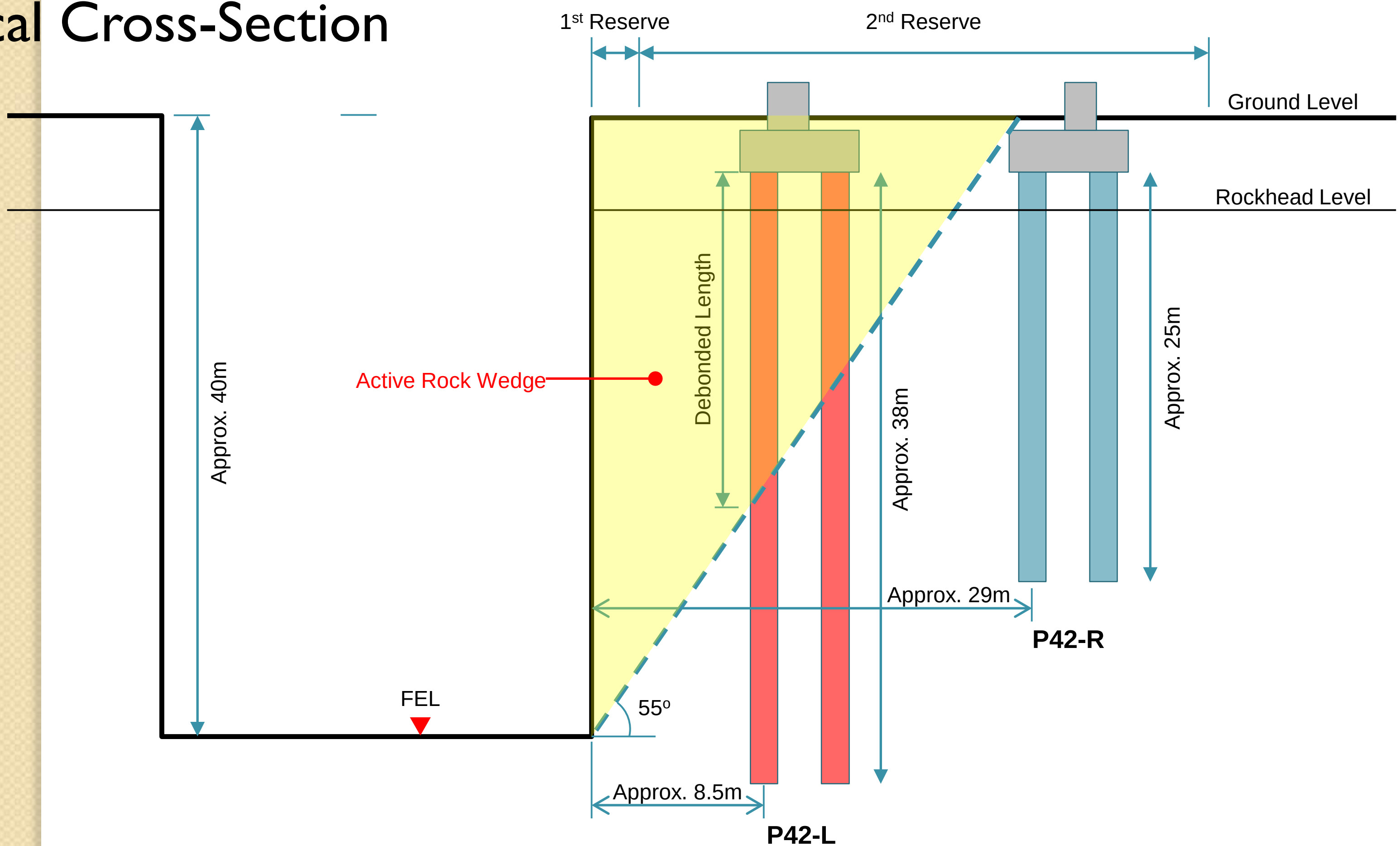
Example of What Could Go Wrong

Example of localized ground loss (rock slip) due to unforeseen rock joint formation behind exposed rock face.

Despite extensive soil investigation and geophysics work were

Entrance B on the 18th June 2018

Typical Cross-Section



Risk Rating Matrix

		Risk Area	IMPACT SEVERITY				
			1	2	3	4	5
			Minimal	Minor	Moderate	Major	Severe / Catastrophic
IMPACT CAPACITY		Financial	<1 mill	>1 mill ≤ 5 mill	> 5 mill ≤ 10 mill	> 10 mill ≤ 20 mill	> 20 mill / > I bill
		Safety	None	First aid required	Medical treatment required	Serious injuries	A fatality case
		Programme	< 4 wks	> 4 wks ≤ 8 wks	> 8 wks ≤ 12 wks	> 12 wks ≤ 16 wks	> 16 wks
		Third Party Impact	Negligible damage	Minor damage some repairs required	Moderate to high damage requires specialist to repair	Significant / permanent damage	Widespread, substantial/ permanent damage
		Environmental Impact	Minor contamination of spoils at works area	Slight contamination of spoils at works area - some precaution's necessary result in slight delay	Contamination/pollution into public space causing public nuisance/discomfort	Major source of contamination causing adverse public health & well being	Catastrophic environmental damage
LIKELIHOOD	5	Almost Certain - happens frequently (more than 10 times within the project)	5	10	15	20	25
	4	Very Likely - could happen frequently (more than 3 times within the project)	4	8	12	16	20
	3	Likely - could happen occasionally (less then 3 times within the project)	3	6	9	12	15
	2	Unlikely - could happen rarely (1 time within the project)	2	4	6	8	10
	1	Very Unlikely - probably will not happen (has never occurred)	1	2	3	4	5

Low
Medium
High
Very High

Risk Assessment

Top 2 risks anticipated due to DUKE3 piling work are:

1) Safety related to rock slip
2) Impact to programme/cost

49

Risk Assessment – Safety Related to Rock Slip

- Likelihood: Category 2/3 [Risk Rating Matrix]
  - Site investigations were carried out according to best practice.
  - Geological mapping was carried out during excavation and the design of rock bolts and shotcrete was done accordingly.
  - However, geological conditions can not all be fully exposed.
- Impact Severity: Category 5 [Risk Rating Matrix]
  - 50-150 workers in any time; therefore, the consequence can be catastrophic if a rock slip occurs.
- Level of Risk: Severe (Cat 5) x Unlikely/Likely (Cat 2/3) = **High (10-15)**

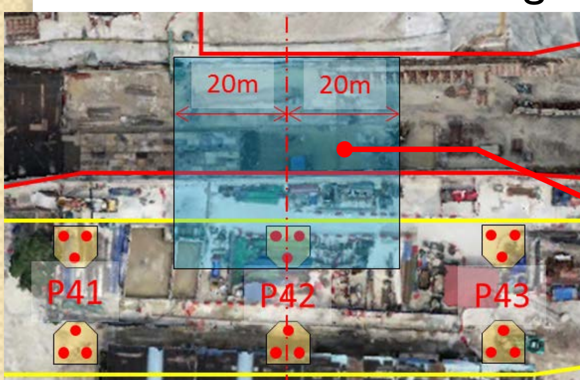
Mitigation Measures

By DUKE 3

- No piling work until the completion of concourse slab.
- One pile at a time after the completion of concourse slab.

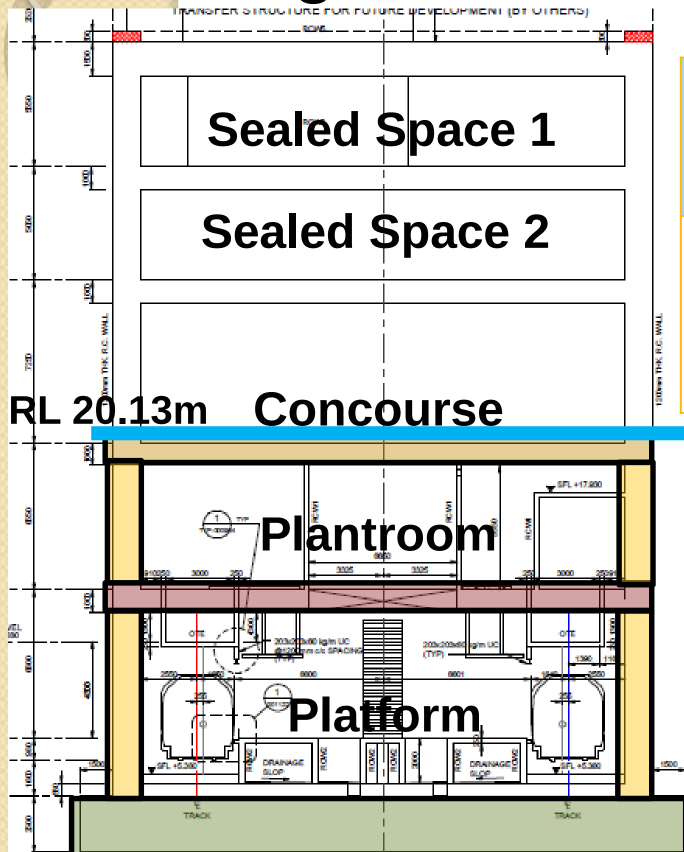
By MGKT

- Remove the workers 20m to either side of piling point. No activity in the 40m cordoned-off zone during active piling.



For example:
when P42-L piling work is on-going, MGKT's no-work zone shall be as highlighted.

Mitigation Measure



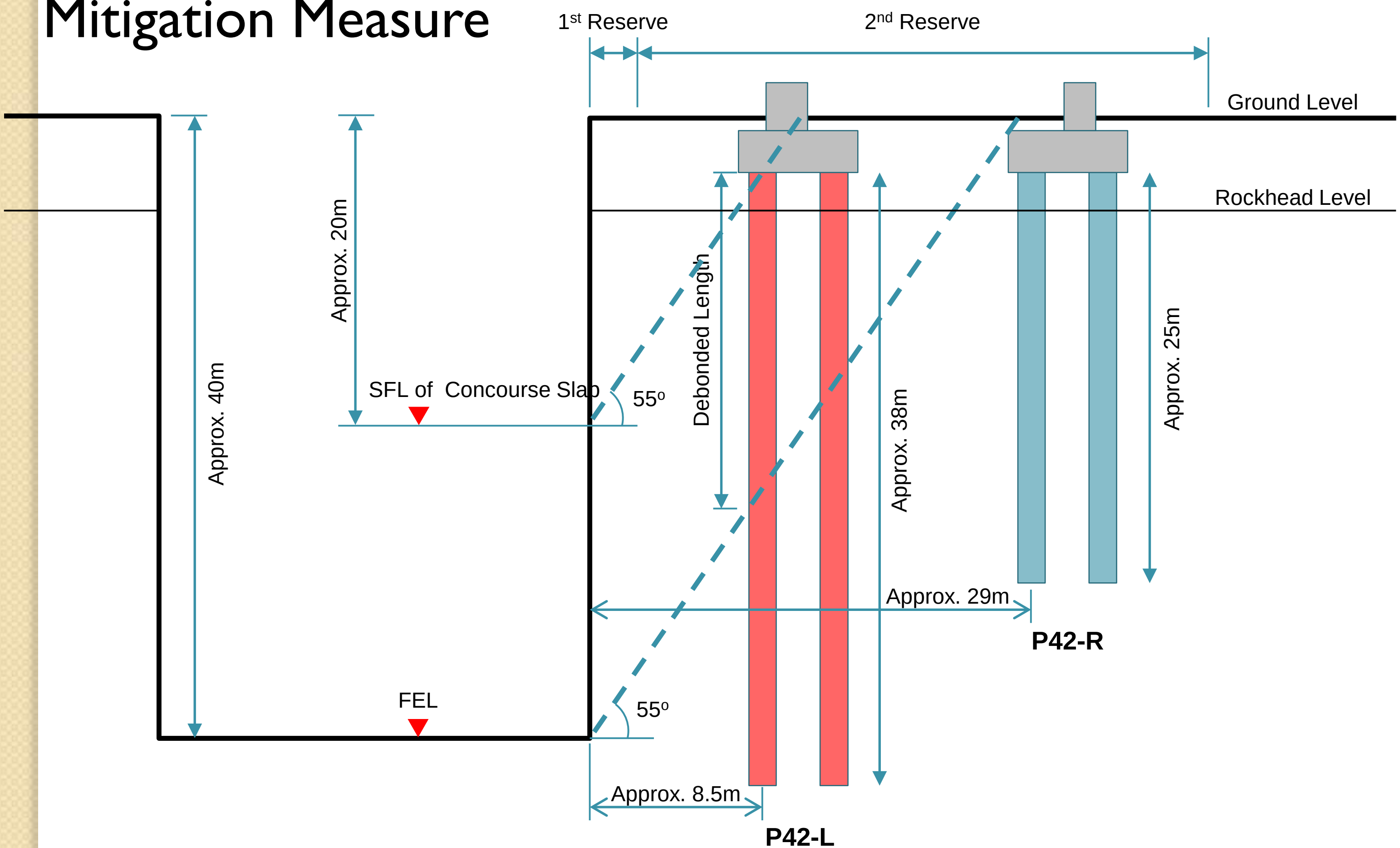
CSLS Box Cross Section

Proposed 2 Level Structural Completion of Station Box
Structural Completion until Concourse Level Slab Level

Note:

1) After the completion of concourse slab, the remaining rock face height is still approx. 20m.

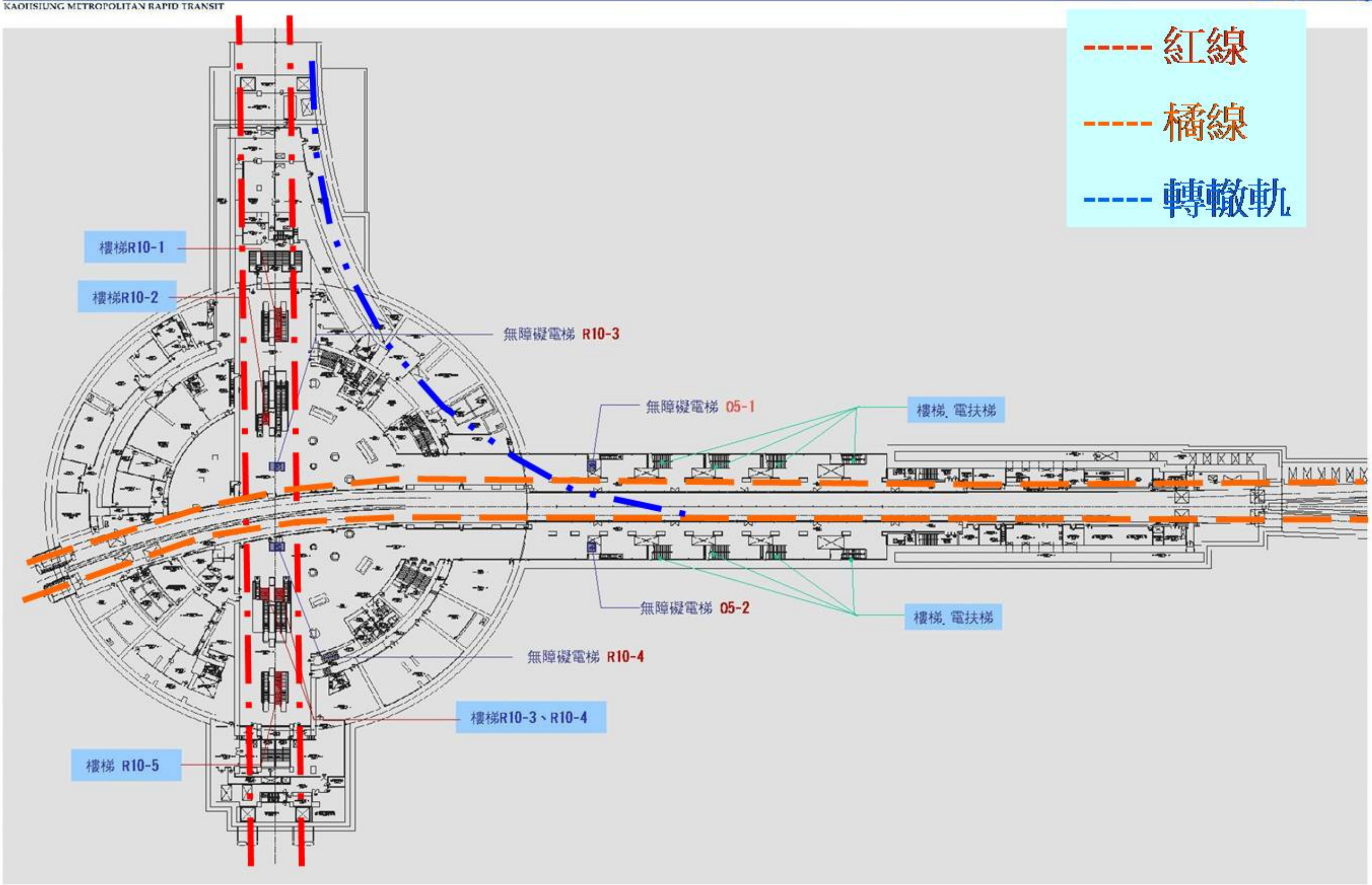
Mitigation Measure



Case History 4: Design Stage

Design of R10 Cofferdam
(Kaohsiung MRT Project)

- Risk assessment: Hazard identification and mitigation measures
  - < 140 m in diameter and 20/27 m deep with no strutting system in urban area
  - < Hoop pressure = Ground water pressure (80%) + Earth pressure (20%)
  - < Verticality of diaphragm wall
  - < Glass-fiber re-bar for TBM-launching
  - < External excavation after the concreting of the circular structure
  - < Geotechnical monitoring system


----- 紅線
----- 橘線
----- 轉轍軌
樓梯R10-1
樓梯R10-2
無障礙電梯 R10-3
無障礙電梯 O5-1
樓梯、電扶梯
無障礙電梯 O5-2
樓梯、電扶梯
無障礙電梯 R10-4
樓梯R10-3、R10-4
樓梯 R10-5

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Risk assessment: Hazard identification and mitigation measures

< 140 m in diameter and 20/27 m deep with no strutting system in urban area

< Hoop pressure = Ground water pressure (80%) + Earth pressure (20%)

< Verticality of diaphragm wall

< Glass-fiber re-bar for TBM-launching

< External excavation after the concreting of the circular structure

< Geotechnical monitoring system

R10 Risk Register

Period	Phenomenum			Influence	Pre RCM					Cause	Measures			Post RCM				
	Large scale	Small scale			Likelihood	Construction Safety		Environment			Contents		In charge	Lidelihood	Construction Safety		Enuironment	
						S	R	S	R						S	R	S	R
Inner soil excavation period	Abnormal behavior of diaphram wall and ring beam	Propriety of design condition	Geologic condition	Diaphram safety is worried because of eccentric pressure	4	3	H	2	M	· Ground unevenness · Lack of geological survey · Underestimate in design	Design	· Make detail geologic survey · Considering unevenness of soil layer,eccentric soil pressure is assumed to be 20% of standard soil pressure	Design dept./Sinotech	1	1	L	1	L
			Ground water level		5	2	H	1	M	· Ground water level fluctuation · Lack of geologic survey · Underestimate in design	Design	· Assume ground water level based on records · Assume water level for dry/rainy season	Design dept Sinotech	1	1	L	0	L
											Monitor	· Adopt automatic monitor system · Pore water pressure gauge	Design dept. Construction dept					

International Standardards

- ISO3100:2009 Risk Management – Principles and Guidelines, supported by “Practice standard for project risk management” 2009 published by Project Management Institute

Risk Management – Key Elements

- Risk Manager風險經理
- Risk Register風險登記冊
- Risk Owner/Action Owner 風險管理人 / 風險行動人
- Top ten risks

Thanks for your attention