مروری بر برخی مشکلات طراحی و اجرایی دو پروژه تونلی شرکت مهندسی ساخت و ساز هیوندای کره جنوبی

دکتر ابراهیم فرخ

مشاور تونلسازی و طراحی و ساخت فضاهای زیرزمینی

انجمن تونل- ۳۰ خرداد ۹۷

معرفی ارائه دهنده

دکتر ابراهیم فرخ

۱۳۹۶-۱۳۹۱: مدیر در تیم سازه های زیرزمینی شرکت مهندسی ساخت و ساز هیوندای کره جنوبی - مسئول بخش پروژه های تونل زنی مکانیزه و مشاوره در زمینه پروژه های تونلی هیوندای

۱۳۹۱-۱۳۸۷: دکتری، مهندسی مکانیک سنگ/استخراج، دانشگاه پنسیلوانیا امریکا

۱۳۹۰ : مهندس تونل در *Brierley Associates*

۱۳۸۷-۱۳۸۶: مسئول گروه مهندسی در قطعات ۳ و ۴ از تونل انتقال آب قمرود

۱۳۸۶-۱۳۸۱: دستیار فنی در قطعات ۳ و ۴ تونل انتقال آب قمرود

فهرست مطالب

۱- معرفی شرکت ساخت و ساز هیوندای کره جنوبی

چارت سازمانی

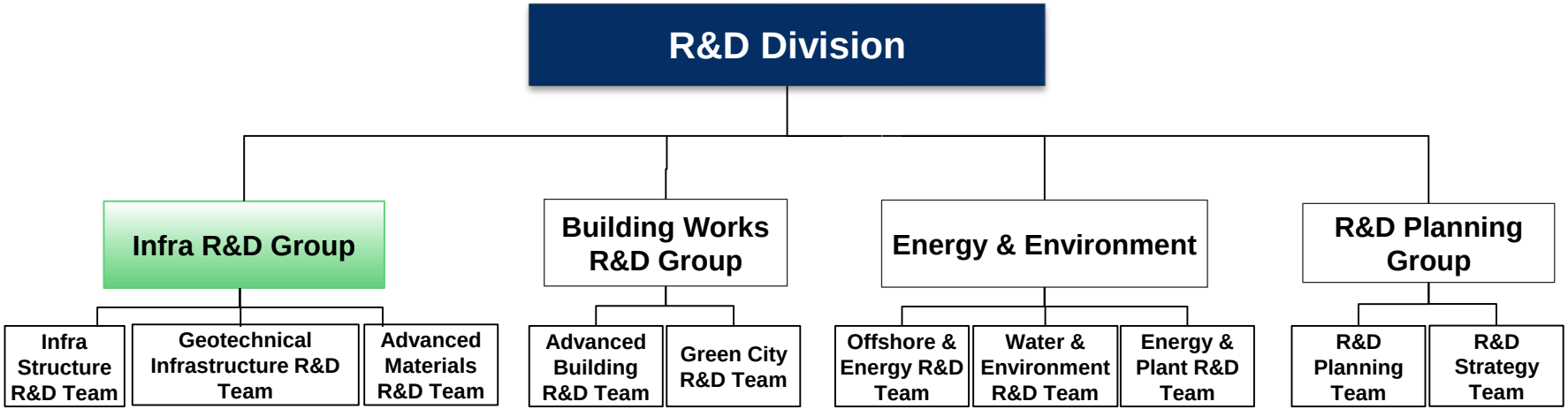
HYUNDAI MOTOR GROUP

- 50 associates
- >200000 members

HYUNDAI ENGINEERING & CONSTRUCTION

- 2011: is acquired
- >5000 members
- >17000 M$

- Civil environment
- Infrastructure
- Plant
- …
- R&D (200 members)



ENR rankings: Top 250 International Contractors

رتبه پیمانکار

Rank		Firm	2016 Revenue (US $ m)		New Contracts in 2016 (US $ m)
2017	2016		Int'l	Total	
1	1	Grupo ACS, Madrid, Spain†	32,598.2	37,333.9	32,598.2
2	**2**	**HOCHTIEF, Essen, Germany†**	**22,927.0**	**24,022.0**	**25,791.0**
3	3	China Communications Constr. Group Ltd., Beijing, China†	21,201.0	70,780.0	36,784.0
4	4	Vinci, Rueil-Malmaison, France†	17,367.3	42,667.9	16,269.6
5	5	Bechtel, San Francisco, Calif., U.S.A. †	16,406.0	24,251.0	4,437.0
6	9	Bouygues SA, Paris, France†	12,257.0	26,354.0	13,107.0
7	7	Technip, Paris, France†	12,113.0	12,230.0	5,484.0
8	10	Skanska AB, Stockholm, Sweden†	12,110.0	15,414.0	15,680.0
9	8	Strabag SE, Vienna, Austria†	12,008.7	14,220.9	13,202.0
10	11	Power Construction Corp. of China, Beijing, China†	11,595.9	43,324.7	27,751.8
11	14	China State Construction Eng'g Corp. Ltd., Beijing, China	10,358.8	124,656.7	17,163.5
12	12	Saipem, San Donato Milanese, Italy†	8,949.0	9,121.0	324.0
13	16	Ferrovial, Madrid, Spain†	8,943.0	11,834.9	14,939.1
14	13	Hyundai Engineering & Constr. Co. Ltd., Seoul, S. Korea	8,664.0	17,694.5	7,307.4
15	19	Petrofac Ltd., Jersey, Channel Islands, U.K.†	7,070.0	7,070.0	1,265.0

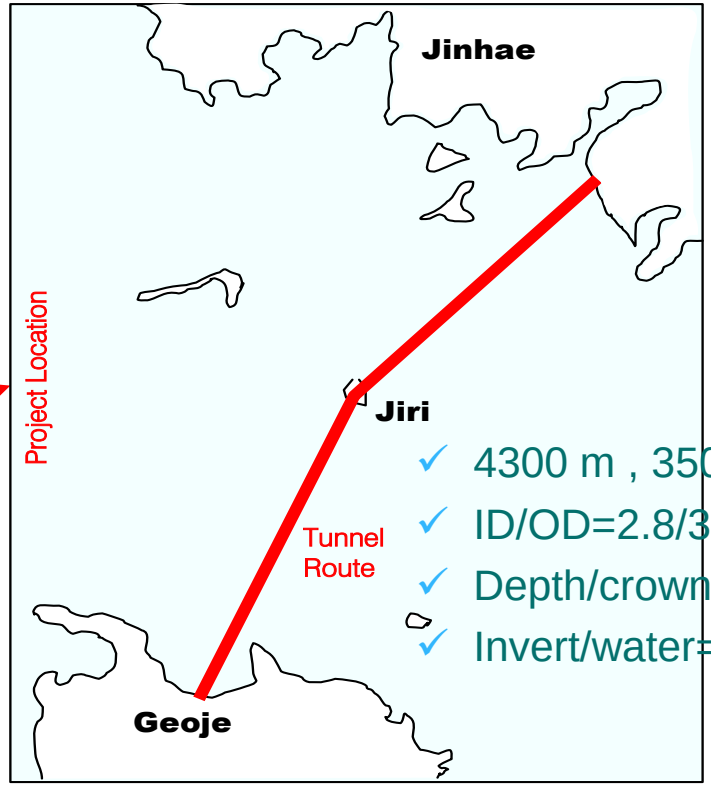
رتبه پیمانکار

HYUNDAI
ENGINEERING & CONSTRUCTION

Year	ENR Rank	Revenue (M$)	% International
2010	23	8876.5	50
2016	13	17694.5	49
2017	14		

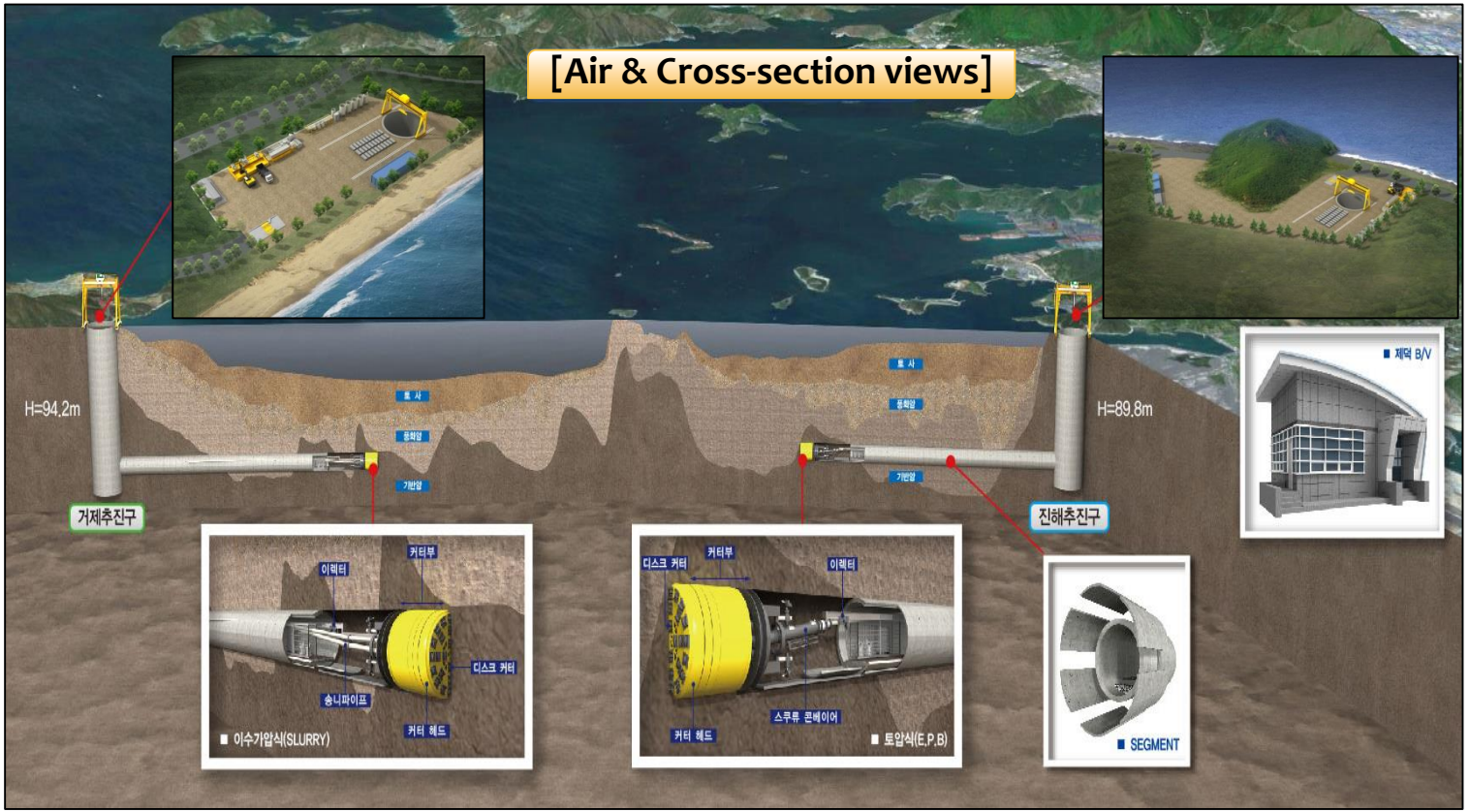
۲- ارزیابی خصوصیات طراحی و عملکرد TBM- تونل زیردریایی Jinhea-Geoje کره جنوبی

موقعیت پروژه

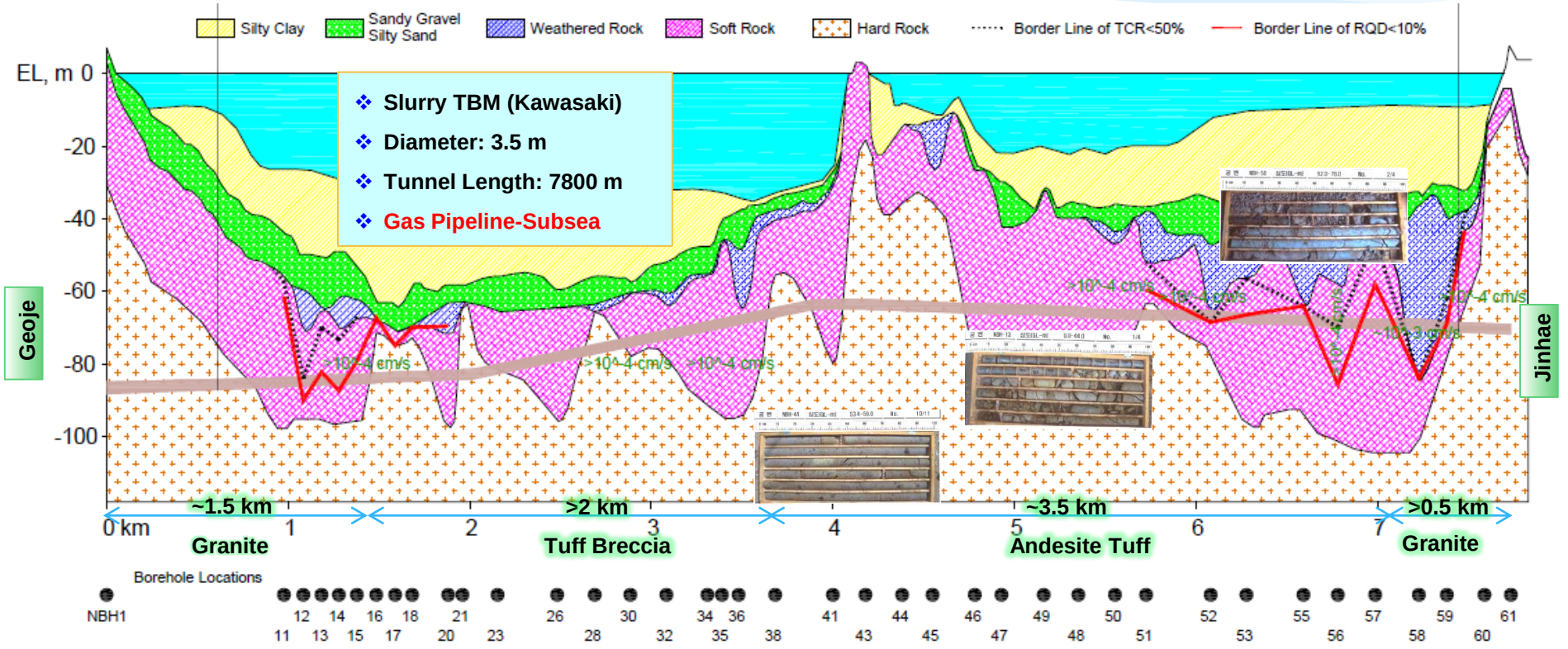


- ✓ 4300 m , 3500 m
- ✓ ID/OD=2.8/3.2 m
- ✓ Depth/crown= 85 m
- ✓ Invert/water= 8.83 bar

نمای کلی پروژه



مقطع زمین شناسی



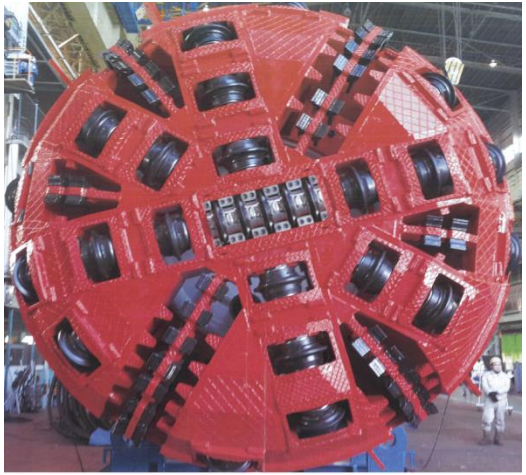
39 vertical borings reached tunnel

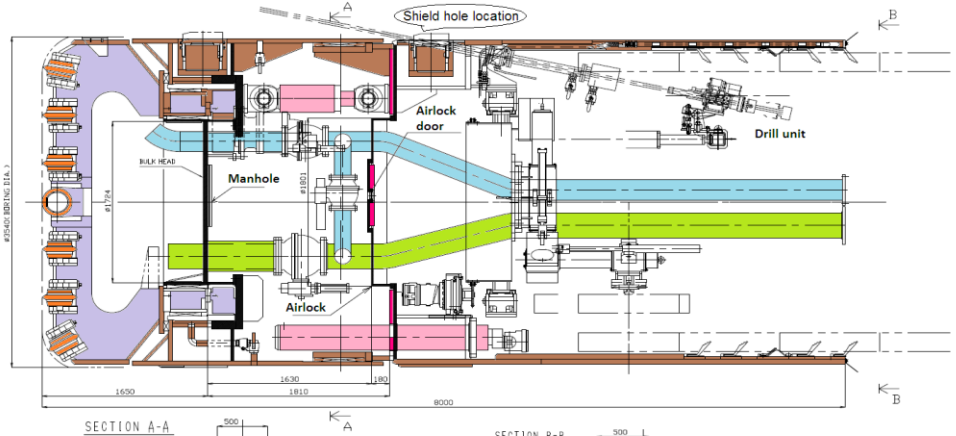
انتخاب دستگاه

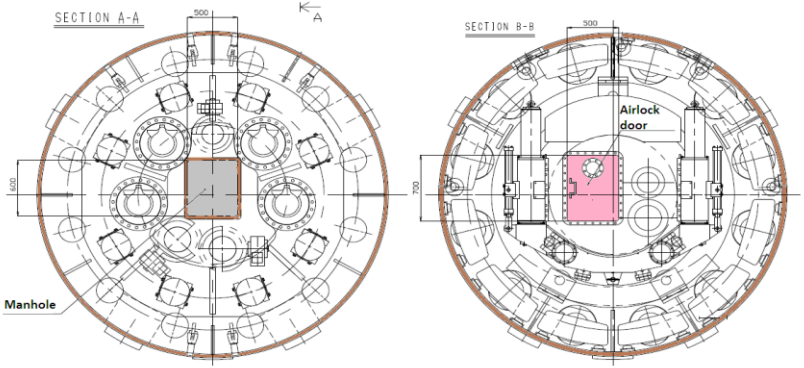
* As per the contract, the tunnel sections were required to be excavated by face pressurized shielded TBMs.
* A regular EPB cannot withstand a potential water pressure of 9 bar
* With an EPB, excavated material conditioning is more difficult when the fine content happens to be very low (e.g. in crushed rock mass with low fine content).
* Hence, a slurry TBM was chosen as the TBM for this tunnel project.

جزئیات طراحی

Working pre/design pre/capacity: 3.0 bar/3.75 bar/2 persons





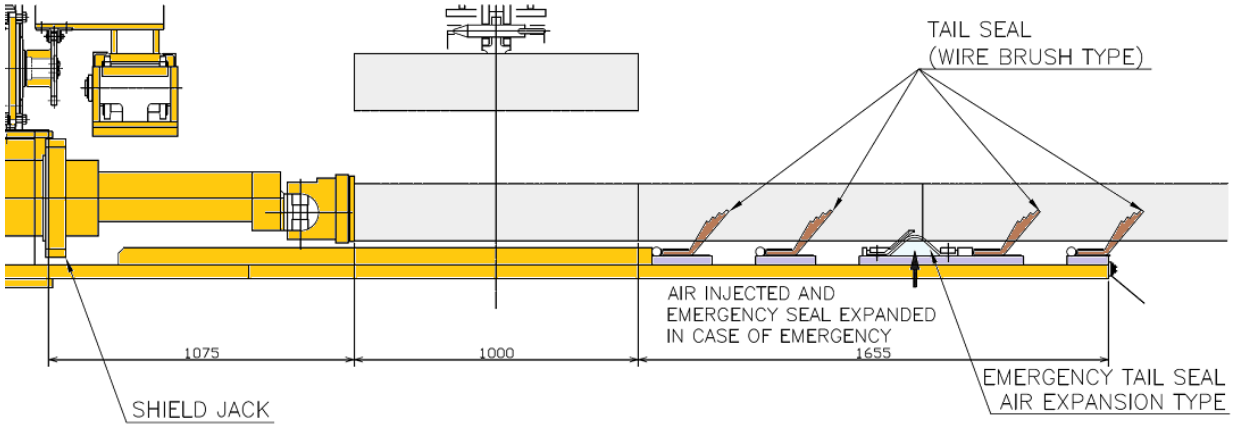


- No. of disc cutters: 27
- Size: 12” – 14” – 15”
- Face cutter spacing: 80 mm
- Tip width: 19 mm

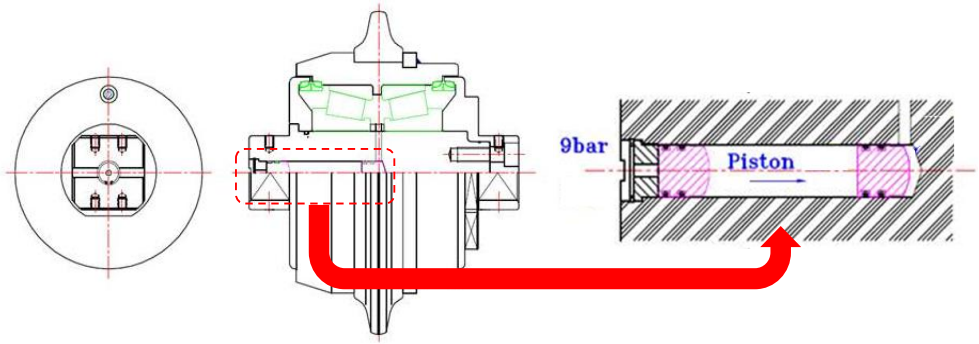
Front shield air lock system and drilling from the shield holes for grouting

جزئیات طراحی

* Tail seal system



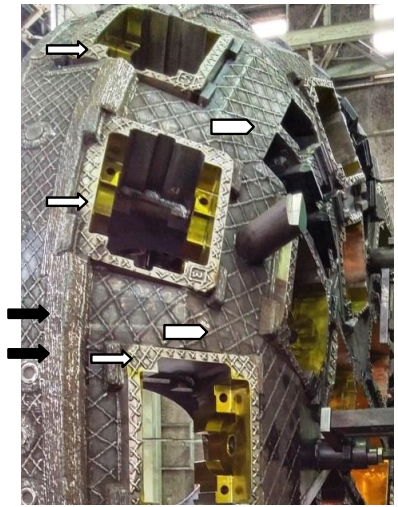
* Pressure compensated disc cutter

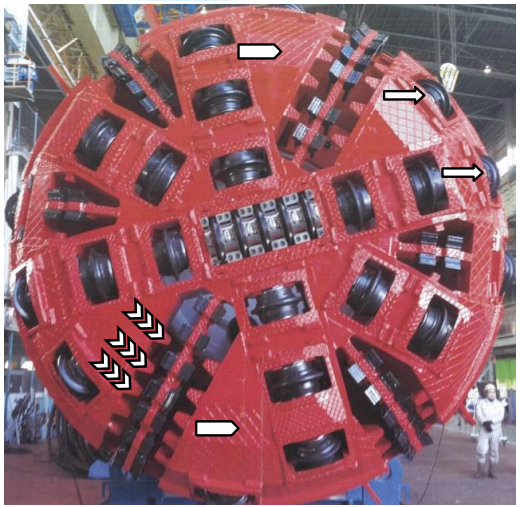


جزئیات طراحی

* Cutterhead wear protection and hard facing

Wear Protection on the cutter head





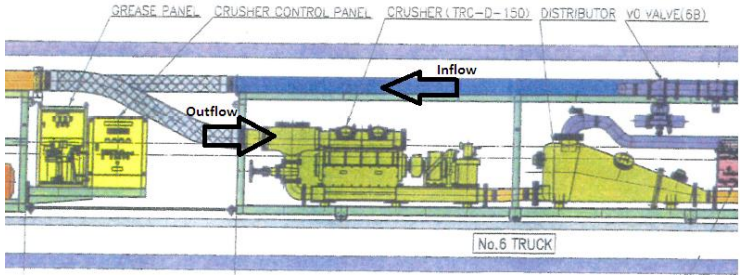
Protection frame for the cutters

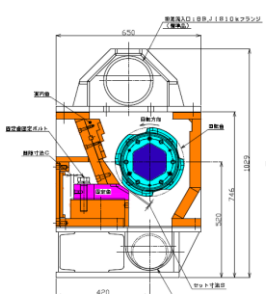
Hard facing

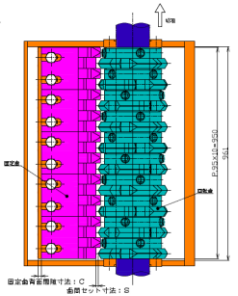
Protection bar for the periphery

Grill bars to control max block size

* Stone crusher used on the sixth truck of the back-up

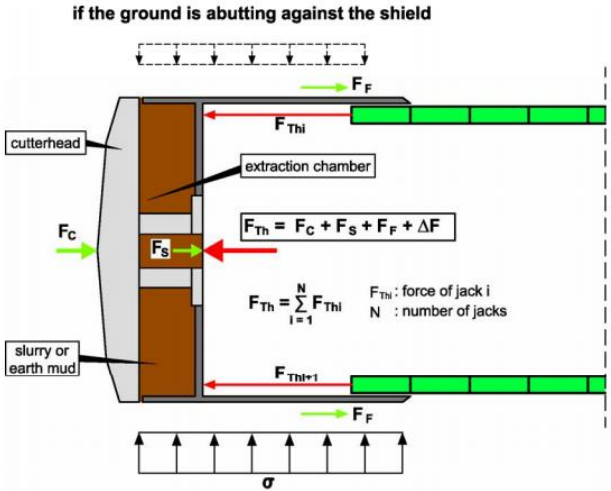




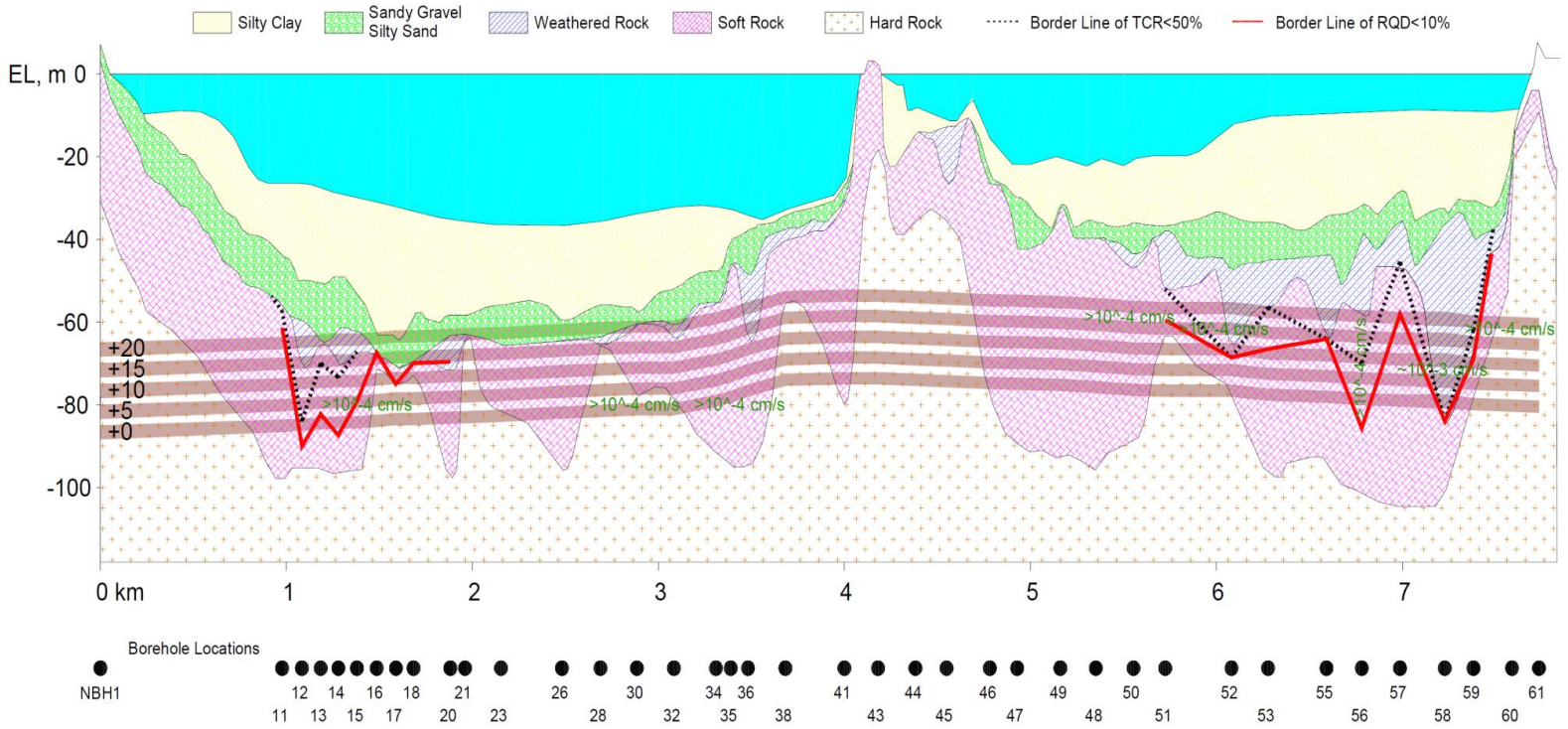


جزئیات طراحی

Item	Explanation	Ton
F1	Friction Resistance btw the ground shield skin	144
F2	Friction Resistance btw segments and shield skin	8
F3	Pulling Force of trailing gear	3
F4	Slurry Pressure on the face @ 8.655 bar	832
F5	Force of excavation tools = 27 * (17.5 ton/cutter)	473
∑	f * (F1 + F2 + F3 + F4 + F5) where f is a safety factor	>1460



بررسی عمق تونل



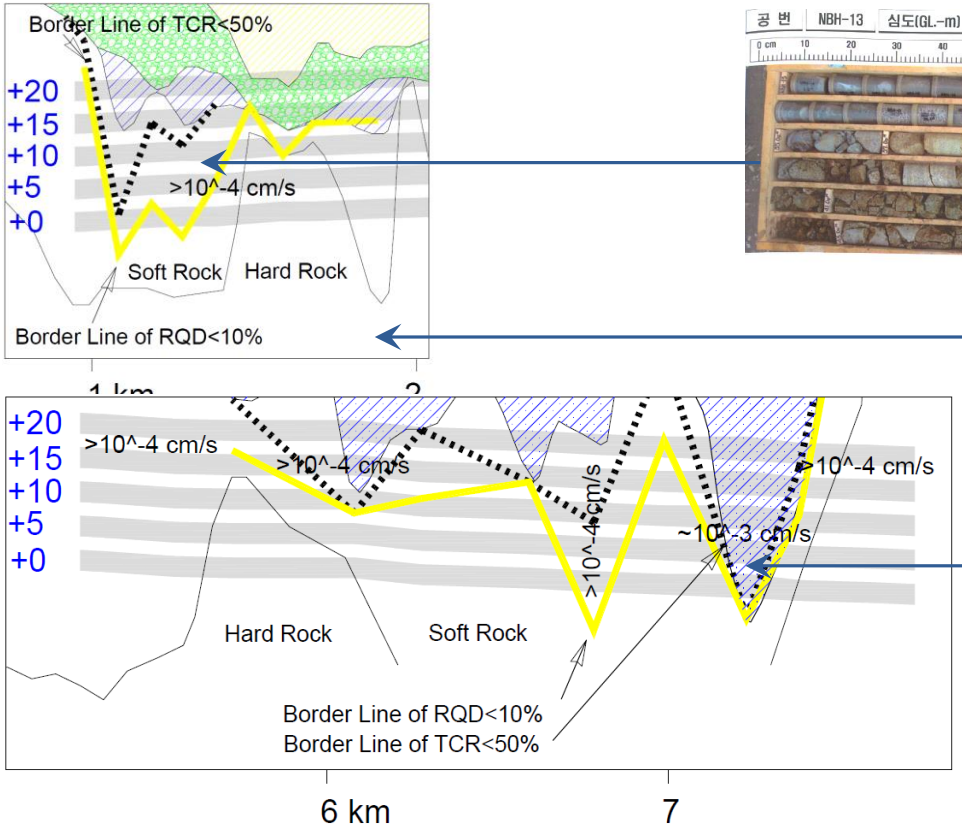
فاکتورها بررسی شده

* 1. Crushed rock:
  * This factor is important to identify potential water inflow pass ways which may cause heavy water inflow and max water pressure in TBM cutter head intervention.

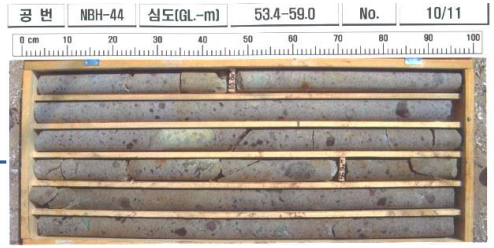
* 2. Low stand-up time:
  * This factor is important to identify potential unstable tunnel face for TBM cutter head intervention.

* 3. High permeability:
  * This factor is important to identify potential high water inflow from the face in TBM cutter head intervention.

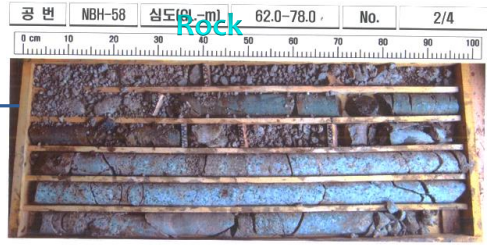
زونهای خرد شده



Soft Rock



Hard Rock

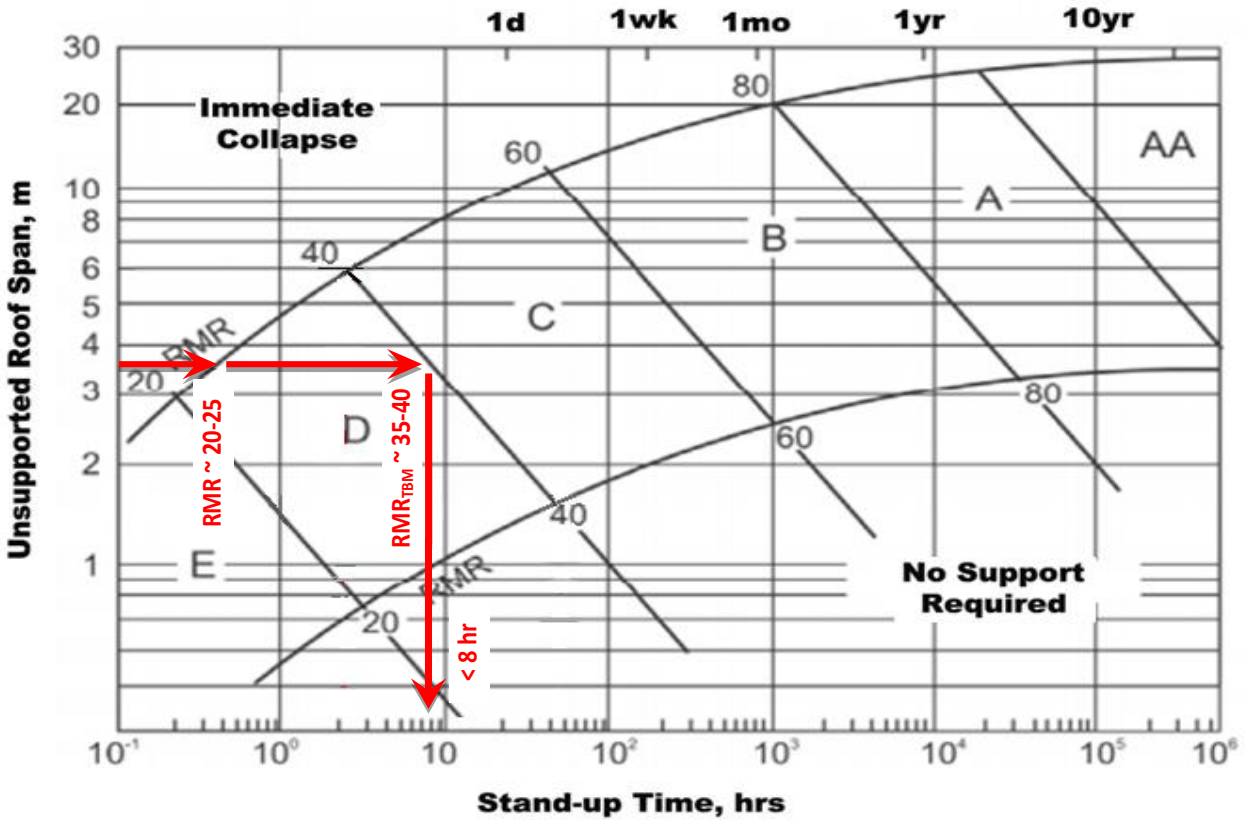


Weathered Rock/Fracture Zone

As tunnel depth decreases the length of tunnel with RQD<10% increases

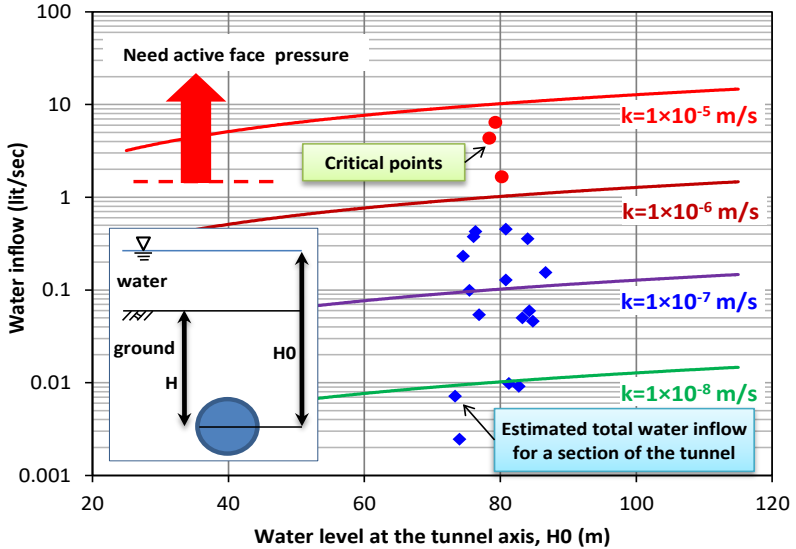
زمان پایداری کم

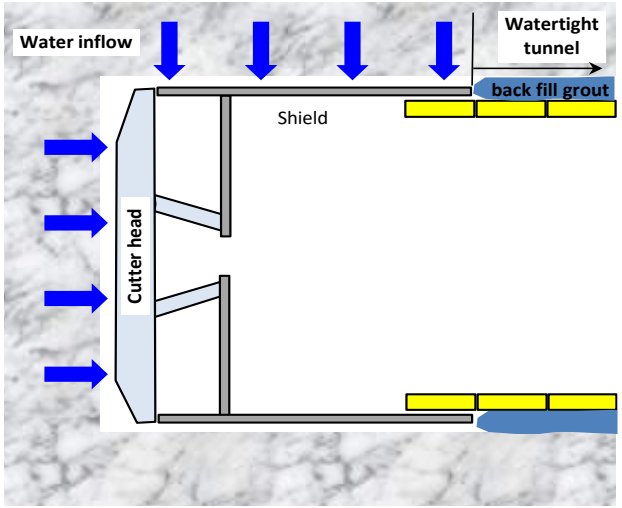
Span: 3.5 m (Tunnel diameter)



نفوذ پذیری بالا

- Water inflow from the tunnel face/walls is directly related to the permeability.
- In this regard we need to consider:
  - Chamber volume and the pumping capacity
  - Water inflow into the tunnel using for example Goodman formula





نواحی بحرانی

NBH No.		11	12	13	14	15	16	17	18	20	21	23	26	28	30	32	34	35	36	38	41	43	44	45	46	47	49	48	50	51	52	53	55	56	57	58	59	60	61
Distance, m			106	104	98	97	103	105	99	146	139	136	261	267	201	198	212	153	86	147	259	249	191	184	200	190	190	212	197	187	263	276	255	252	198	223	197	181	176
RQD	+20	58	0		0												47	30	0	32	26	43	41	100	56	90	26	38		20	0	6	0		0	0	0	100	88
		33		0							40				34		78		18		46		71			78		75		0				30	14			90	73
	+15	41		0	0	6					44	52	27		73	6	48	60	18	93	77	40	92	100	31	89	45	90	14	47	0	0	0	0	21	0	0	70	45
					0		65		0		57	90	24	59					21		86	48	95	94	53	71	63		13	80		14		70	25		43		50
	+10	54	0	0	5	4	77	64	16	14	88	83	0	78	71	61	71	24	50	85	86	83	86	97	40	0	63	89	13	100	0	55	6	0	21	0	43	100	8
			0			4	92	5	77		83	91		87	17	44	64					84		92	7	38		77	0	74				0			34		
	+5	13	6	0	31	4	93	48	100	63	97	97	71	55	31	23	90	58	16	59	51	95	89	100	18	61	55	90	3	83	45	36	32	21	0	0	17	100	16
		19	3	8		0		70	76	0	56	40					17	86		50			84			46	52	58			28	53	21	0	13		72	66	
	+0	31	10	50	53	12	98	83	57	62	82	92	63	81	68	62	89	4	82	84	55	95	77	94	32	58	49	58	0	86	0	25	11	9	21	0	68	100	56
				27	0	43	77				72		46	68		84		67	47		78	83		97				71	0	82	24			13					85
TCR	+20	100	23		43												100	100	61	100	100	100	100	100	100	100	100	98		99	11	90	40		37	5	30	100	100
		100		48							96				94		100		100		100		100			100		100		78			90	97			100	100
	+15	98		70	43	77					100	87	92		100	67	100	100	80	100	100	100	100	100	100	100	94	100	95	100	27	73	55	32	100	7	68	95	100
					50		100		91		100	100	100	100					68		100	100	100	100	100	100	100		95	100		87		100	100		100		97
	+10	95	57	68	100	99	90	100	56	100	100	100	27	100	100	97	94	99	100	100	100	100	100	100	94	100	100	100	50	100	59	100	100	38	100	12	100	100	95
			21			99	100	95	100		100	100		100	92	94	100					100		100	97	100		97	71	100				35			100		
	+5	100	21	71	100	99	100	100	100	100	100	100	100	100	100	100	100	100	81	100	100	100	100	100	97	100	100	100	55	100	100	100	100	91	86	13	100	100	100
		100	23	64		95		100	100	12	100	100				100	100		100			100				100	100	100			100	100	100	61	100		100	100	
	+0	100	100	100	100	95	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	98	98	100	100	95	100	93	100	100	75	85	3	100	100	100
				90	20	100	100				100		100	100		100		100	100		100	100		100				100	73	100	100			90					100
RMR	+20	56													34		38	26		34	35	46	65	87	44	60	36	39	16	15		18		31	16			87	73
		34		23							53				37		46	34		62	40	46	75	82	39	60	35	61	16	15		18		31	19			87	73
	+15	34		13		15					53	43	21		64	14	41	64		62	66	46	82	82	39	56	43	64	16	45		19		15	19		32	80	49
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	+10	47	15	13	17	15	67	52	29		70	54	12	68	64	60	48	49	41	72	65	72	87	87	39	31	43	63	21	75	16	52	16	13	16		17	87	27
		55	15	13	19	15	71	16	54	14	70	62	48	70	19	33	46	52	41	62	58	79	79	87	21	39	48	61	21	68	16	52	16	13	16		43	87	46
	+5	19	15	13	32	15	73	51	67	57	73	62	48	61	32	24	60	50	25	62	46	87	79	92	36	54	48	66	16	72	36	37	39	16	18		24	92	29
		19	15	13	29	27	73	63	52	14	63	41	63	61	32	24	57	19	47	62	46	87	79	82	31	49	48	66	16	72	22	52	27	16	18		67	75	58
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		31	18	25	19	41	68	82	48	57	69	77	45	66	64	66	60	54	34	72	67	82	69	87	42	39	43	57	16	72	22	15	21	13	21		65	92	82
k	+20																					2.1						1.4											
10^{-5}cm/sec		1.2																				0.6						1.4					48						
	+15	1.2																				0.6											48						
		1.1																				0.4		7.4				1.1			19		42		0.3			
	+10	1.1				-				0.1												0.4		7.4				-			19		42		0.3			
		0.9				-		1.1		0.1			0.1									0.1		3.4				-	19		3.5		45		-			18
	+5	0.9		9.1		-		1.1		0.1			0.1	22	9.3			8.9				0.1		3.4				-	19		3.5		45		-			18
		0.7		9.1		18	-	0.5		0.1			0.1		4.5			8.9				0.1		2.6				-	4.6		0.6		48		-			19
	+0	0.7		0.6		18	-	0.5		0.1			0.1	1.3	4.5			4.3				0.1		2.6				-	4.6		0.6		48		-			19
		0.5		0.6		3.5	-	-		0.1			0.1	1.3	2.2			4.3				0.1						-	4.1				47		-			

RQD< 10%

→Crushed rock, potential water inflow pass way

TCR< 50%

→Crushed rock, potential water inflow pass way

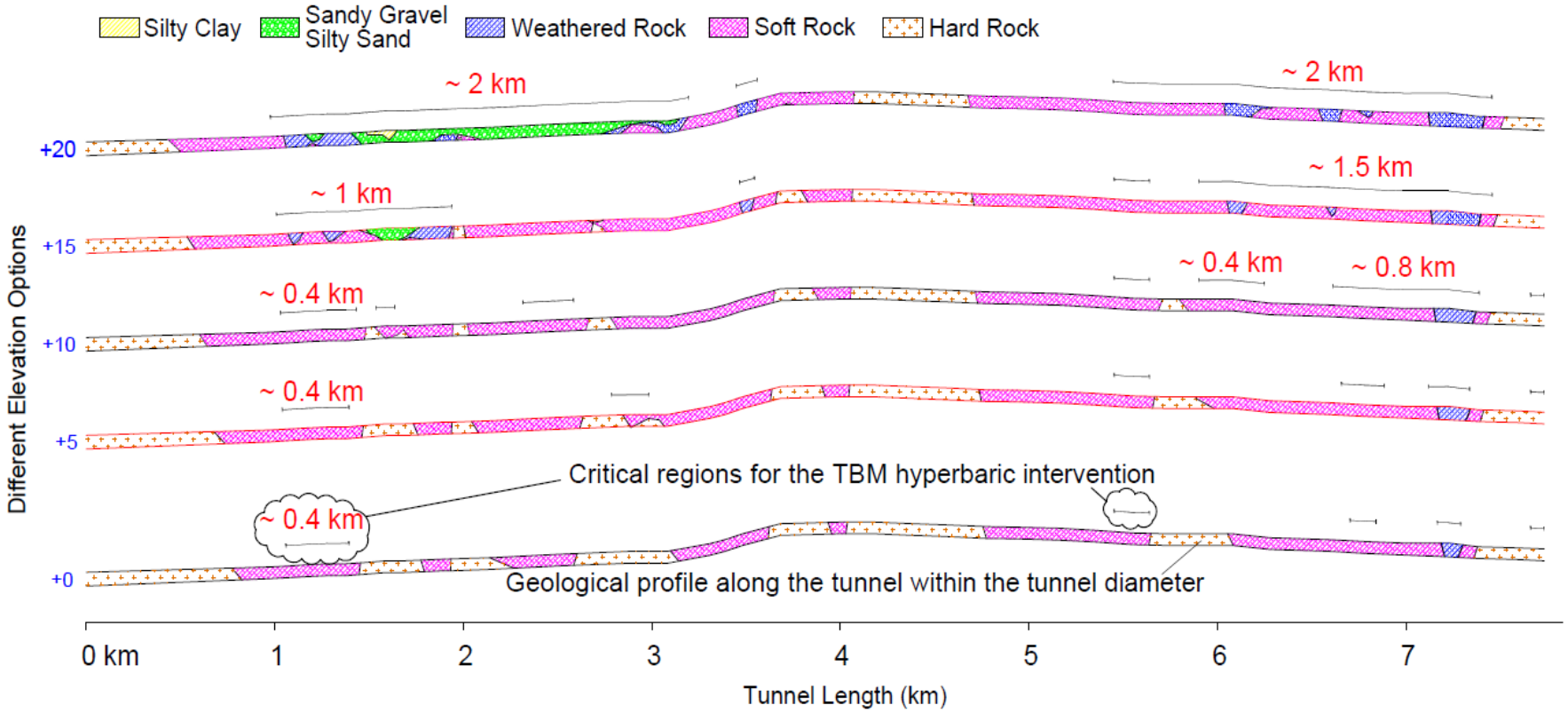
RMR< 22

→very low stand-up time, need for active face pressure in intervention

k>10^{-4} cm/sec

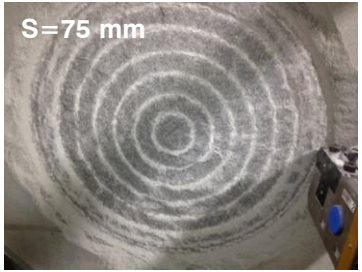
→high water inflow,, need for active face pressure in intervention

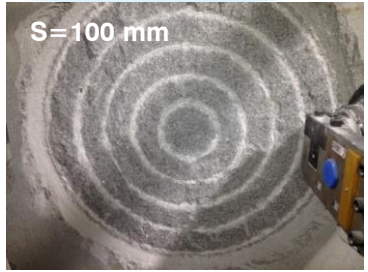
نواحی بحرانی

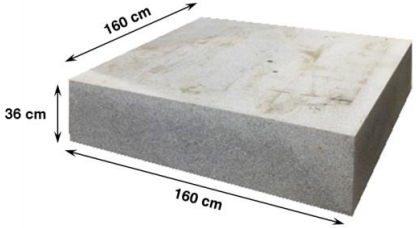


آزمایش نفوذ-RCM

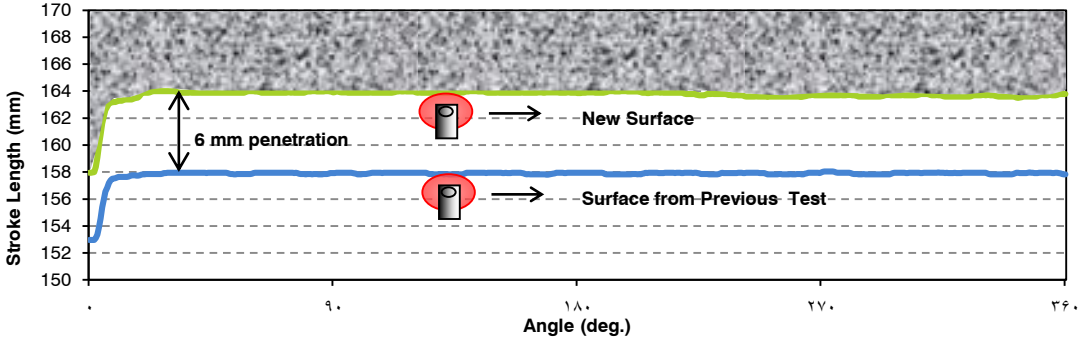
Rotary Cutting Machine Developed in HDEC

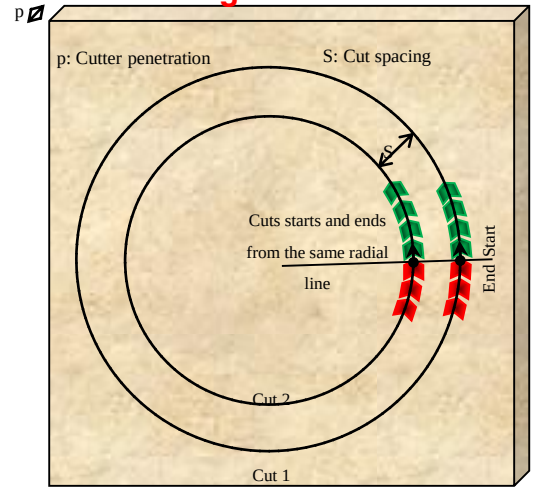






- Constant Penetration Mode
- Constant Normal Force Mode
- RPM Change Mode





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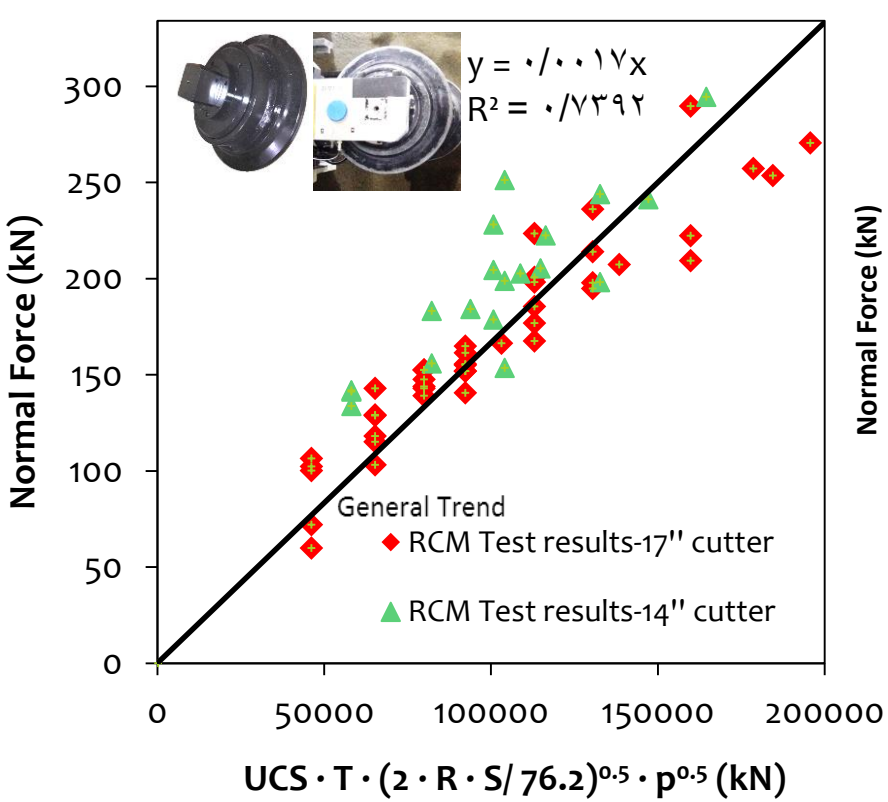

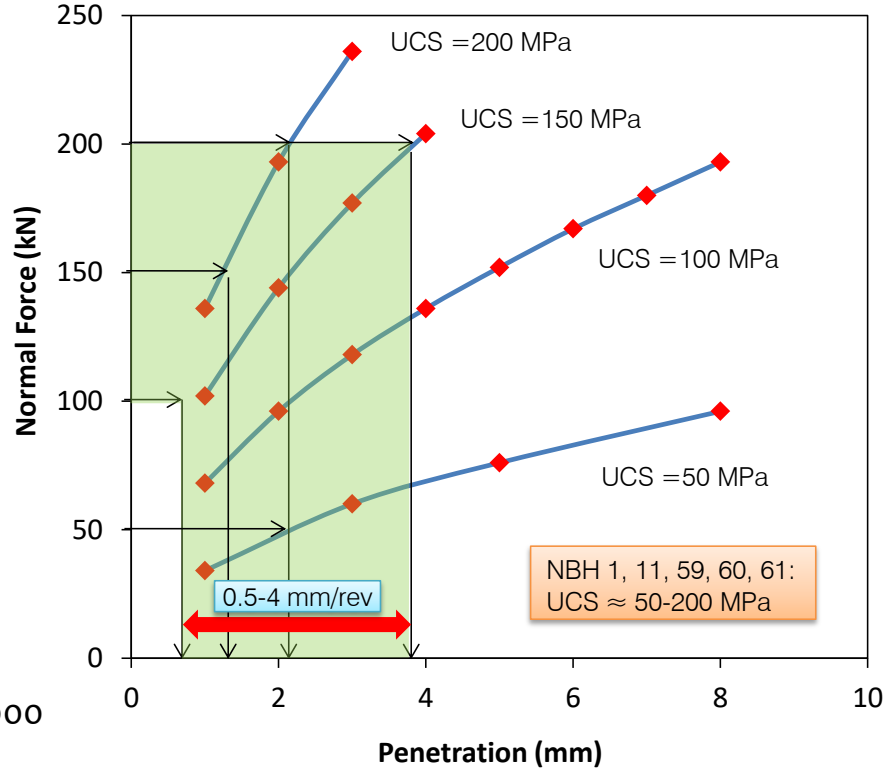

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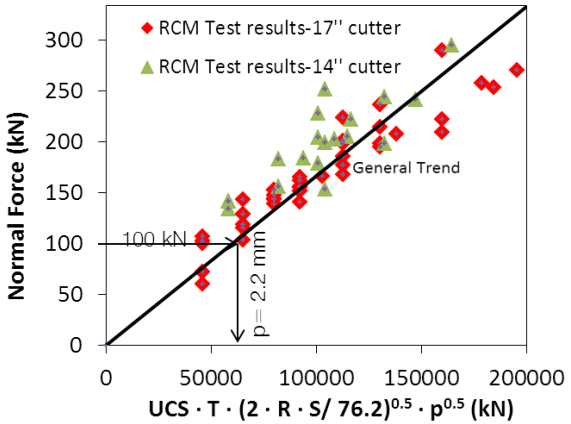

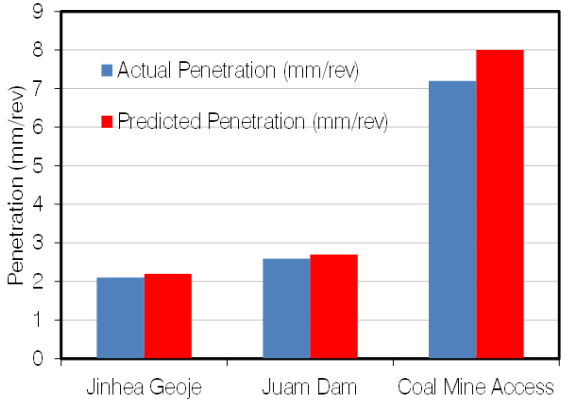

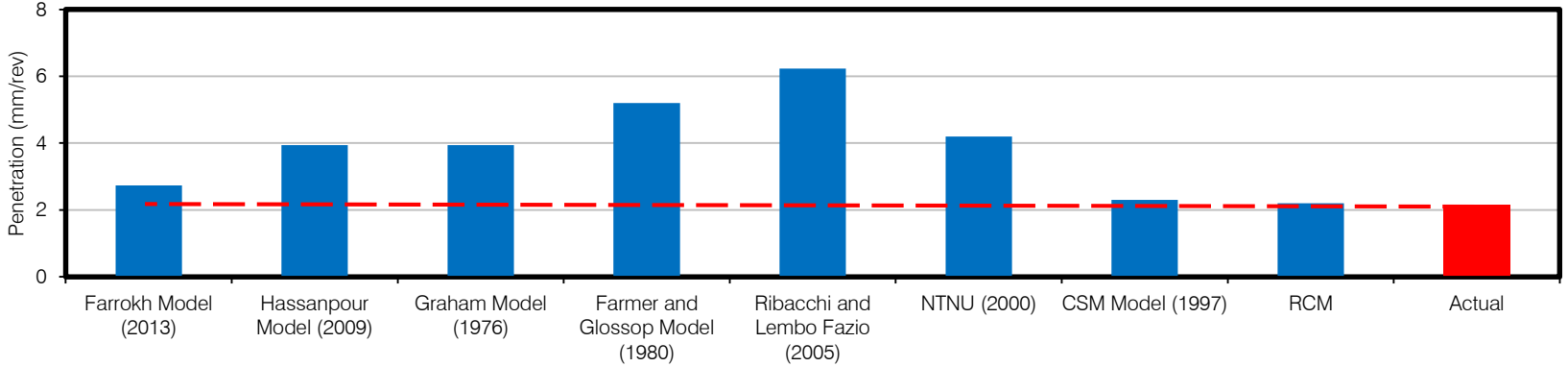

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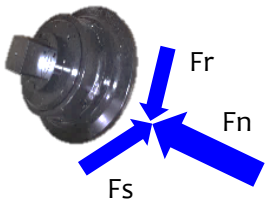
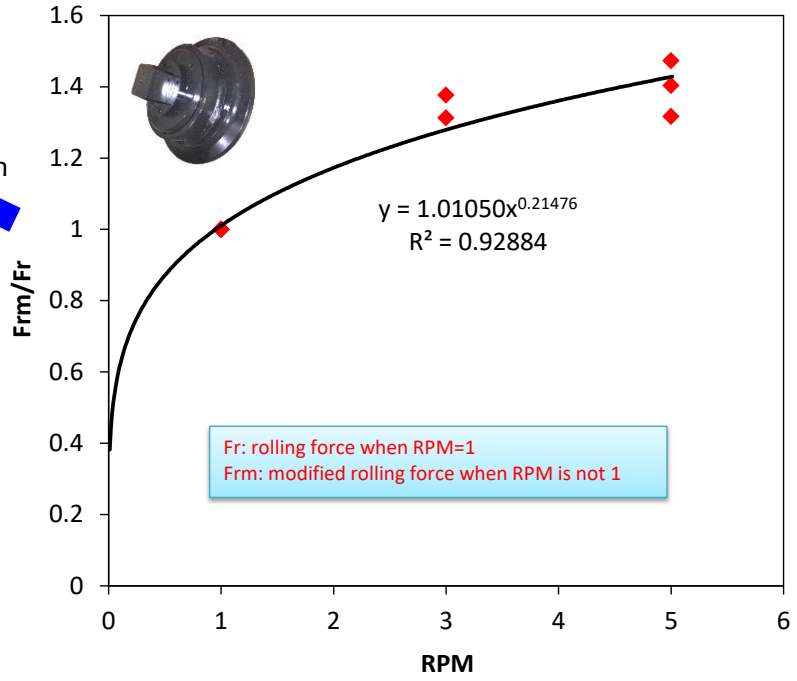
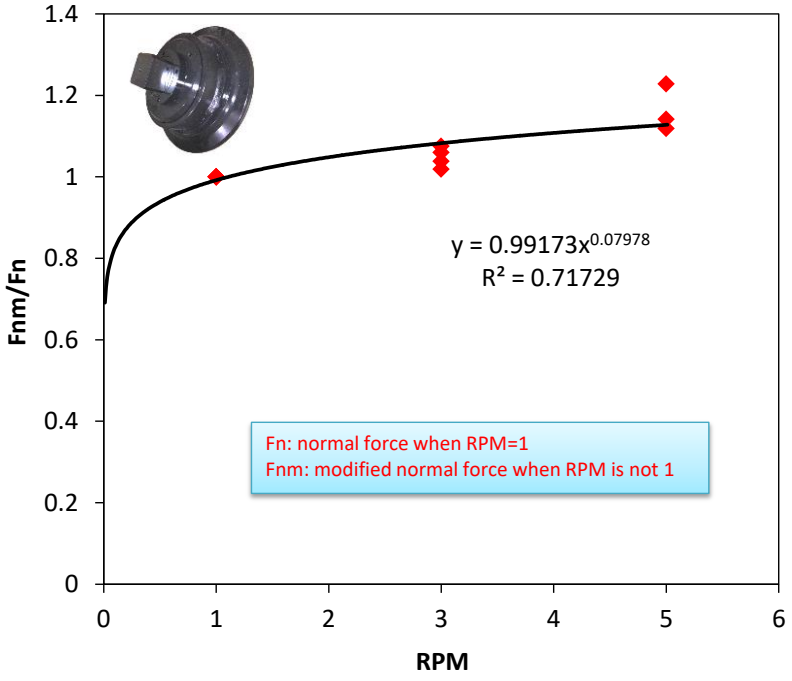
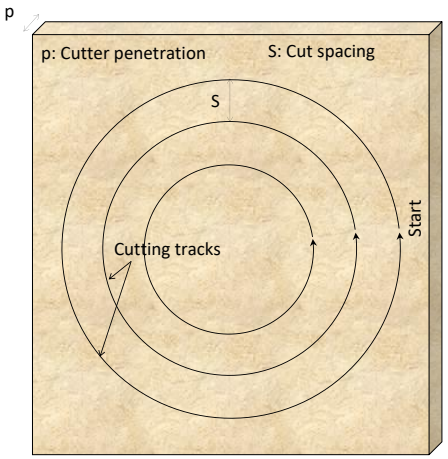


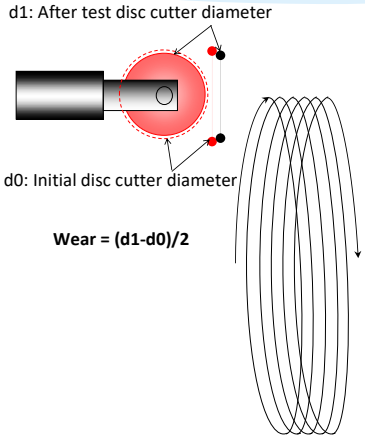




اندازه گیری سایش

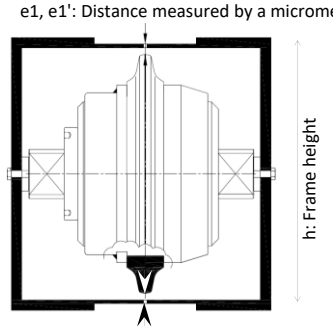


Cutting tracks with the disc cutter



Wear = (d1-d0)/2

Cutting path for one of the tracks



d0: initial disc cutter diameter

d0 = h - (e1 + e2)

d0 = h - (gap)

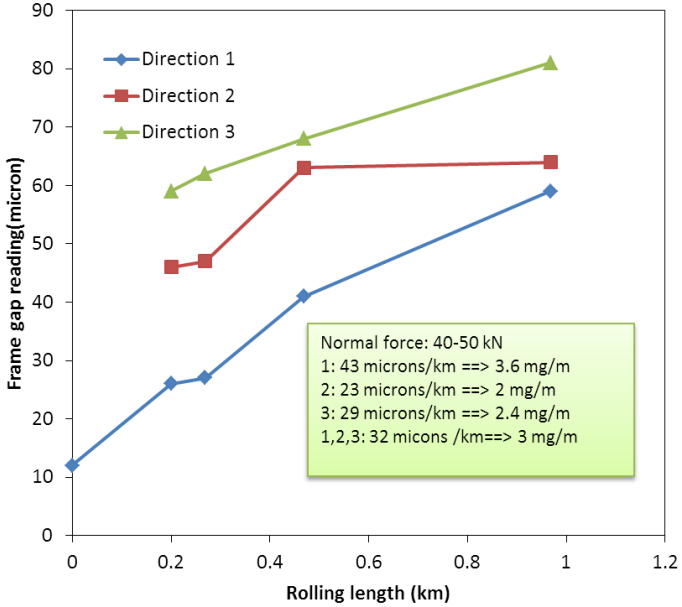
d1: disc cutter diameter after a test

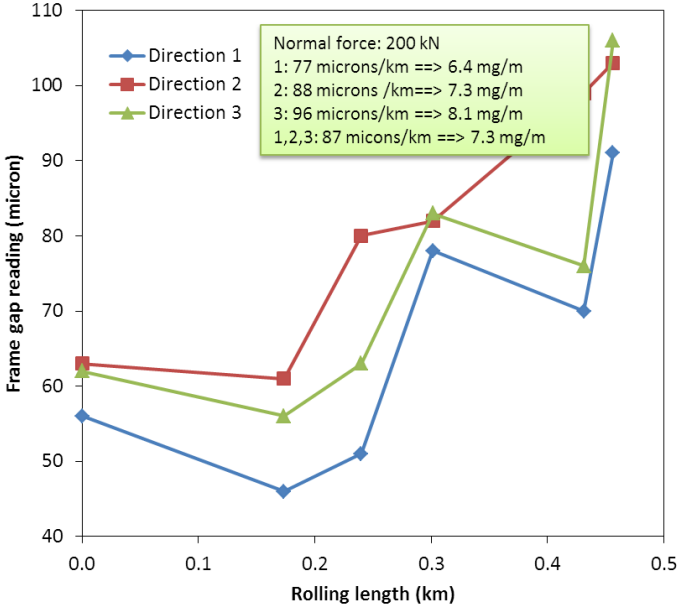
d1 = h - (e1' + e2')

d1 = h - (gap')

Wear = (d0-d1)/2 = (gap'-gap)/2

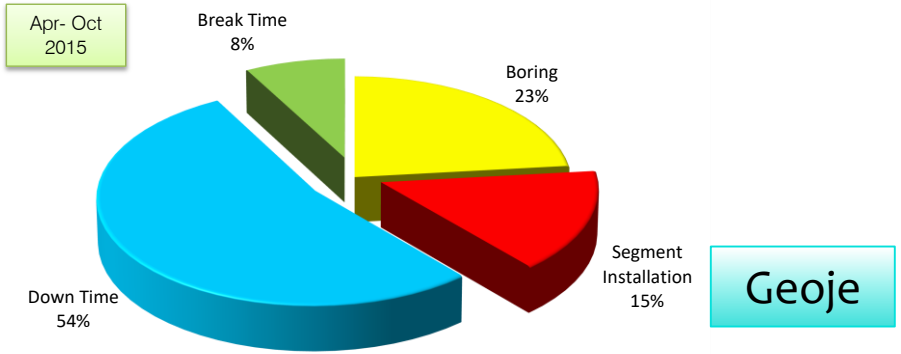
اندازه گیری سایش و تعیین فواصل توقف

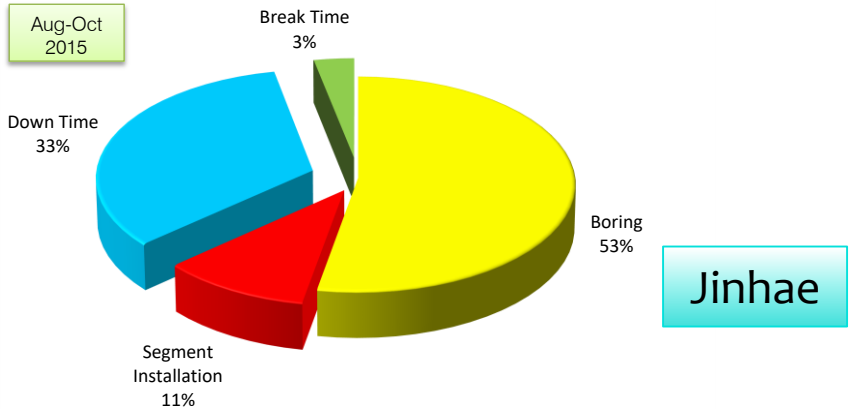


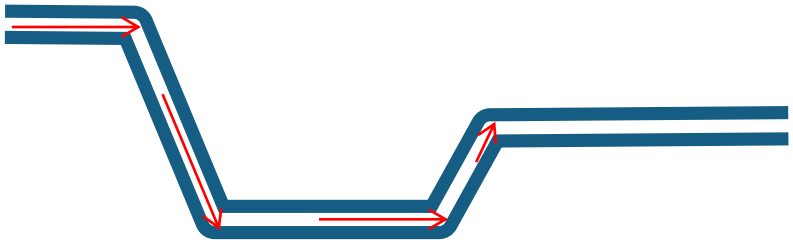


* Using 2 mm/rev for the TBM penetration and 10 mm permissible tip loss
* Fn: 200 ➔ 87 micron/km ➔ 229 km/gage cutter ➔ Max interval length 42 m ➔ actual interval length was around 35 m

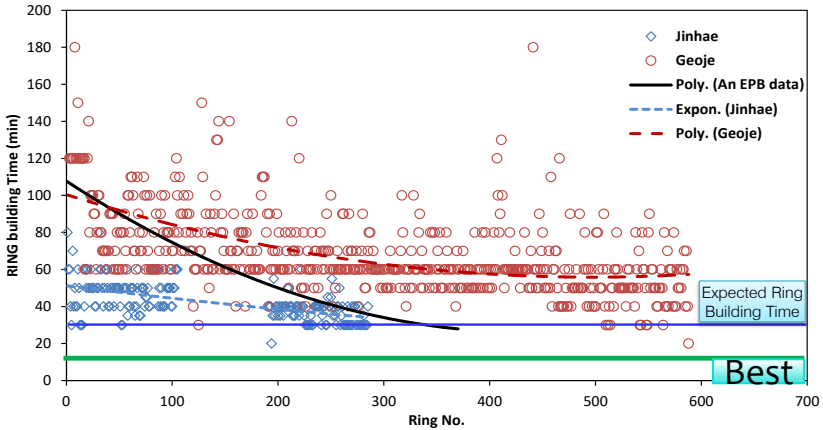
بررسی بهره وری





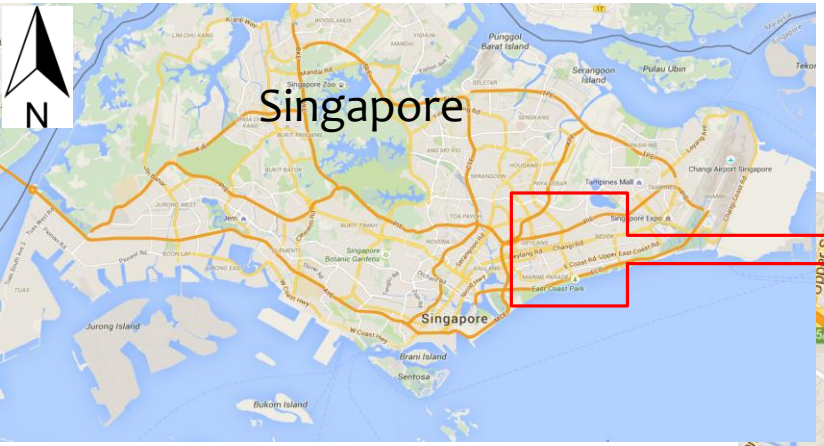


Improving curves and connections and steel quality for critical areas

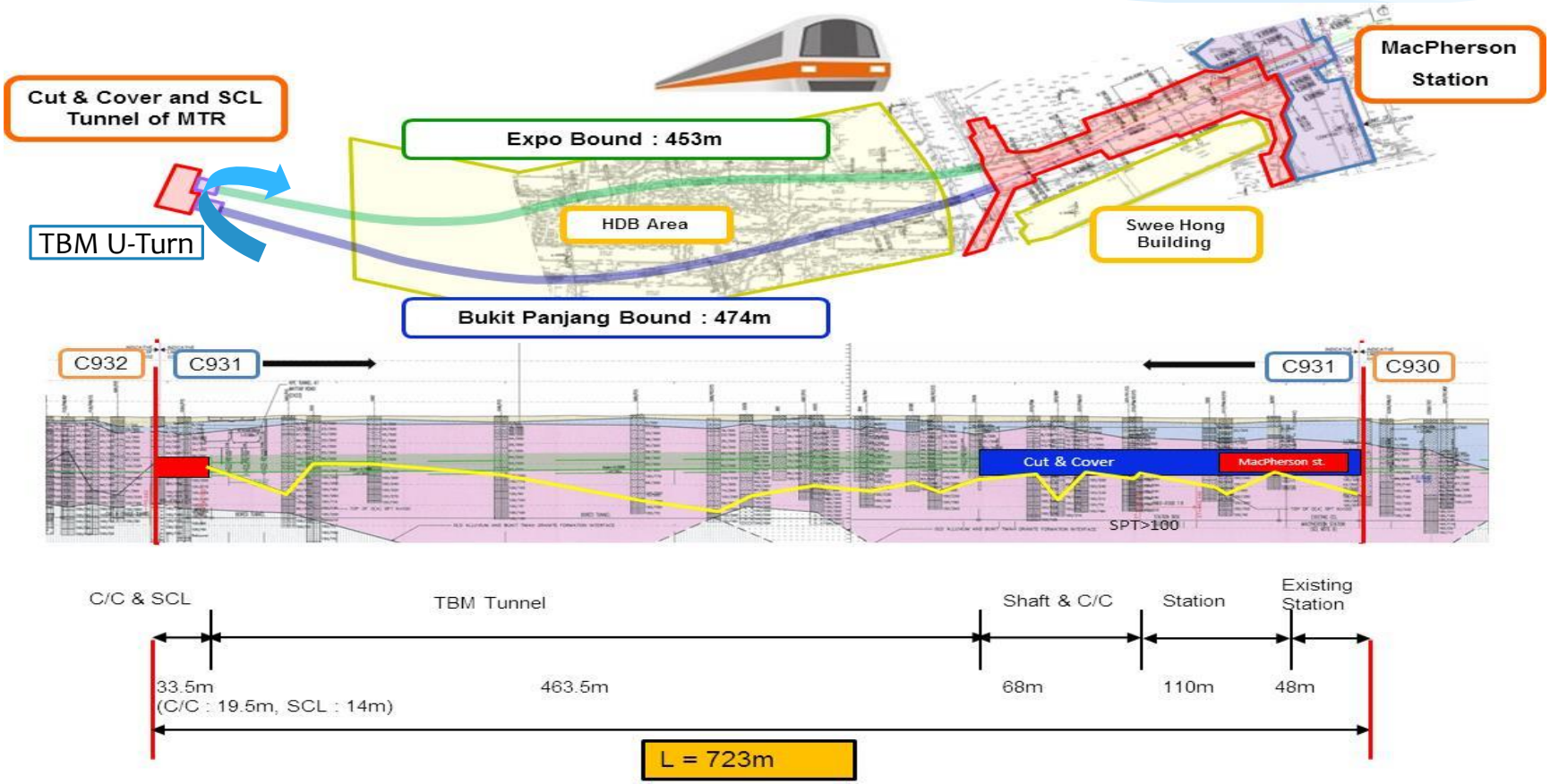


۳- مشکلات حین اجرای تونل متروی DTL3 C931 سنگاپور

موقعیت پروژه

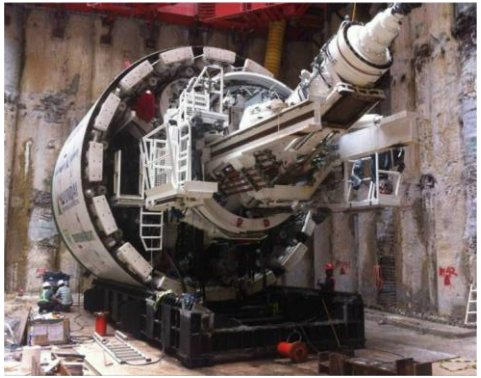


مقطع زمین شناسی



TBM

- TBM Type: EPB (Herrenknecht)
- Diameter: 6.6 m
- Tunnel Length: 927 m
- Subway tunnel (2 lines)
- Overburden: ~22 m
- Geology: very dense silty or clayey sand



TBM Inside

Assembly of Segment

February 2014
Tunnel Breakthrough – Bukit Panjang Bound

March 2014
Expo Line Launching

انتخاب دستگاه

* Soil size distribution:
* Permeability coefficient: Max $1x10^{-7}$ m/s, fits well within the application area of EPB
* Water pressure: The maximum pore water pressure at the tunnel axis in this project is less than 3 bar and it was suitable for the EPB application.

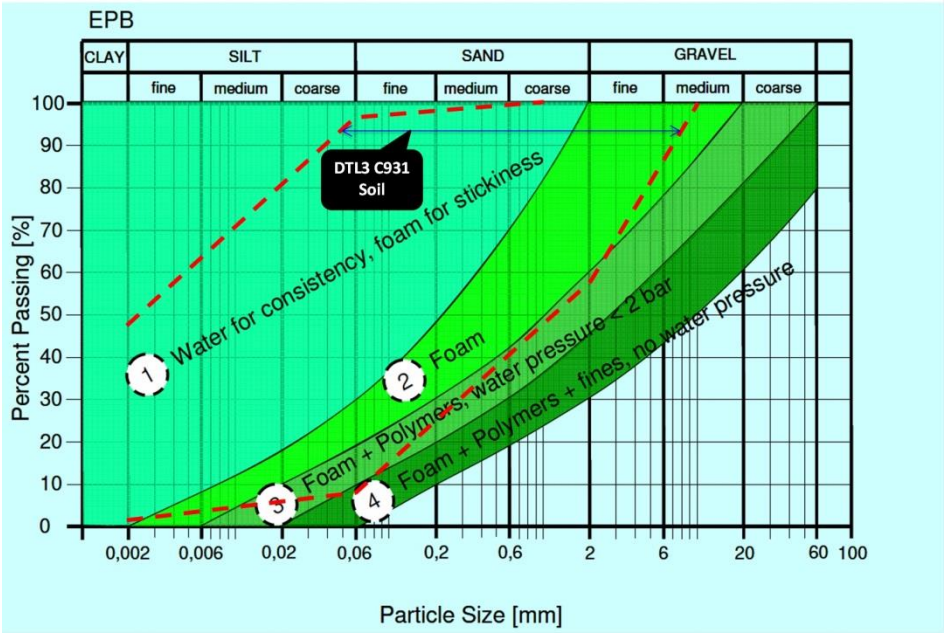
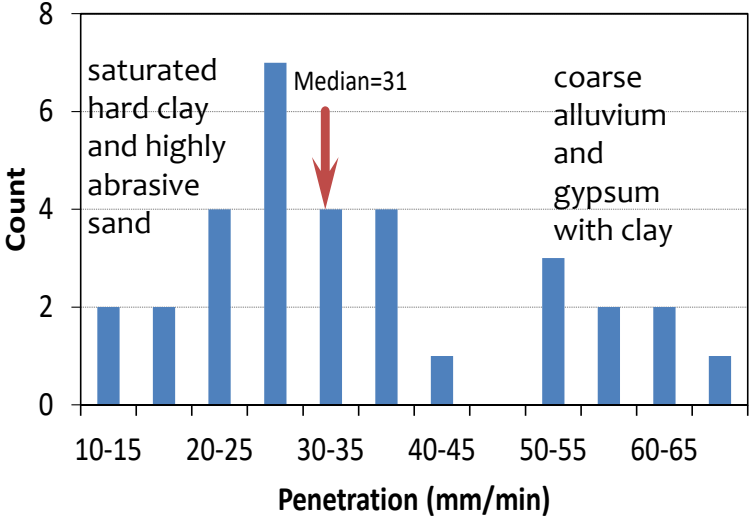
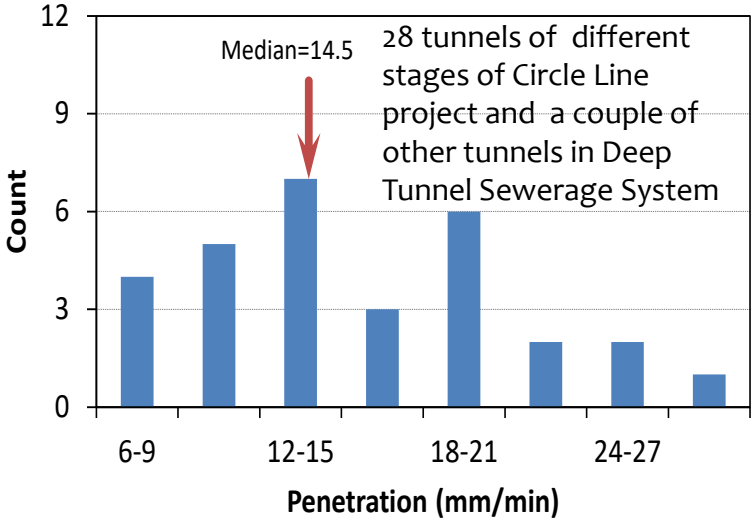


Chart from Thewes (2009)

برآورد عملکرد



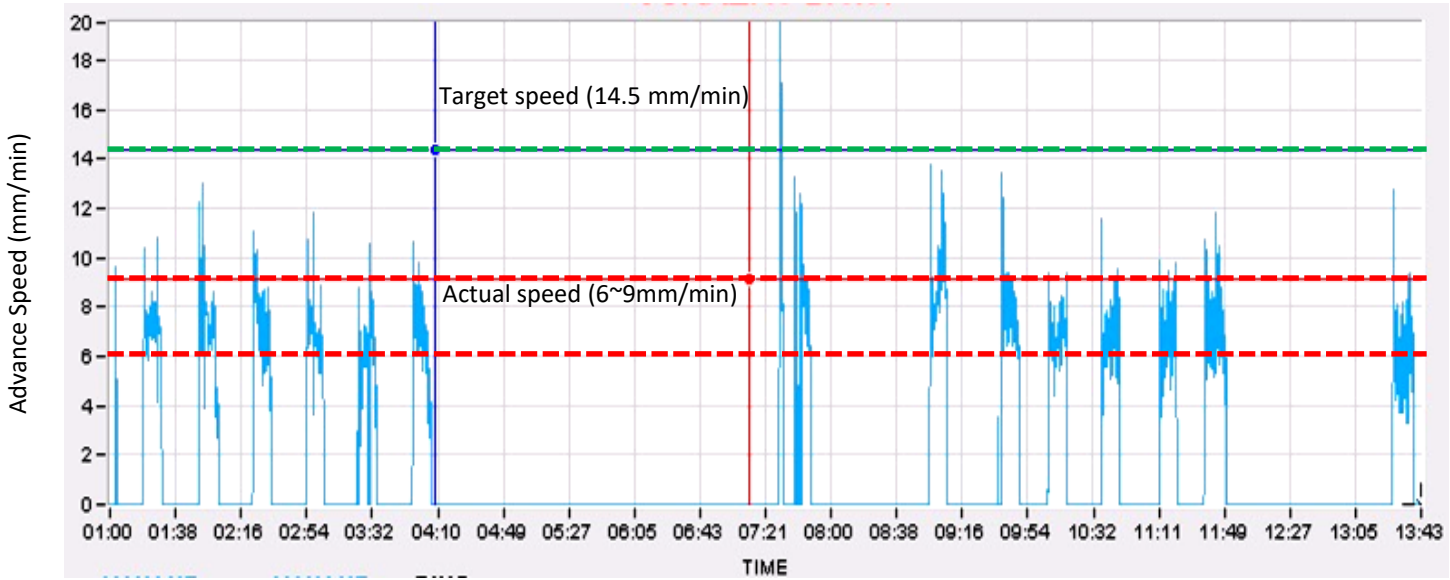
EPB machines of diameter of 5-8 m



Singapore EPB machines of diameter of 6.6 m

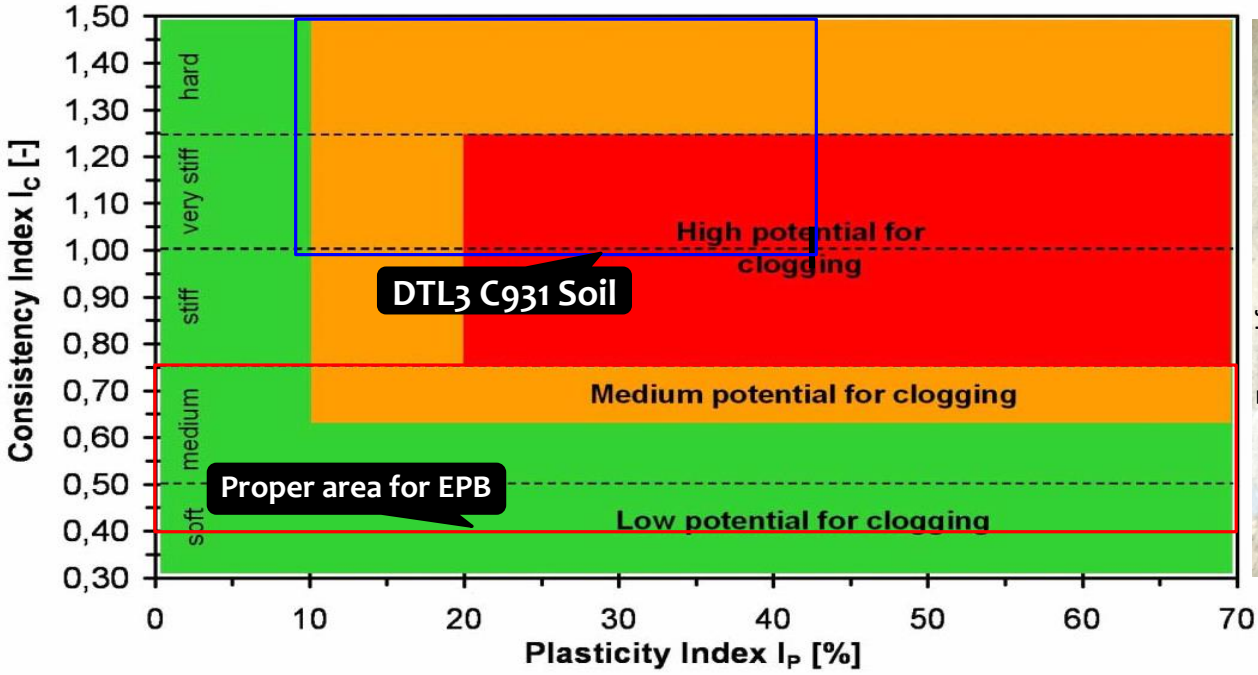
عملکرد واقعی

* Initial TBM penetration rate



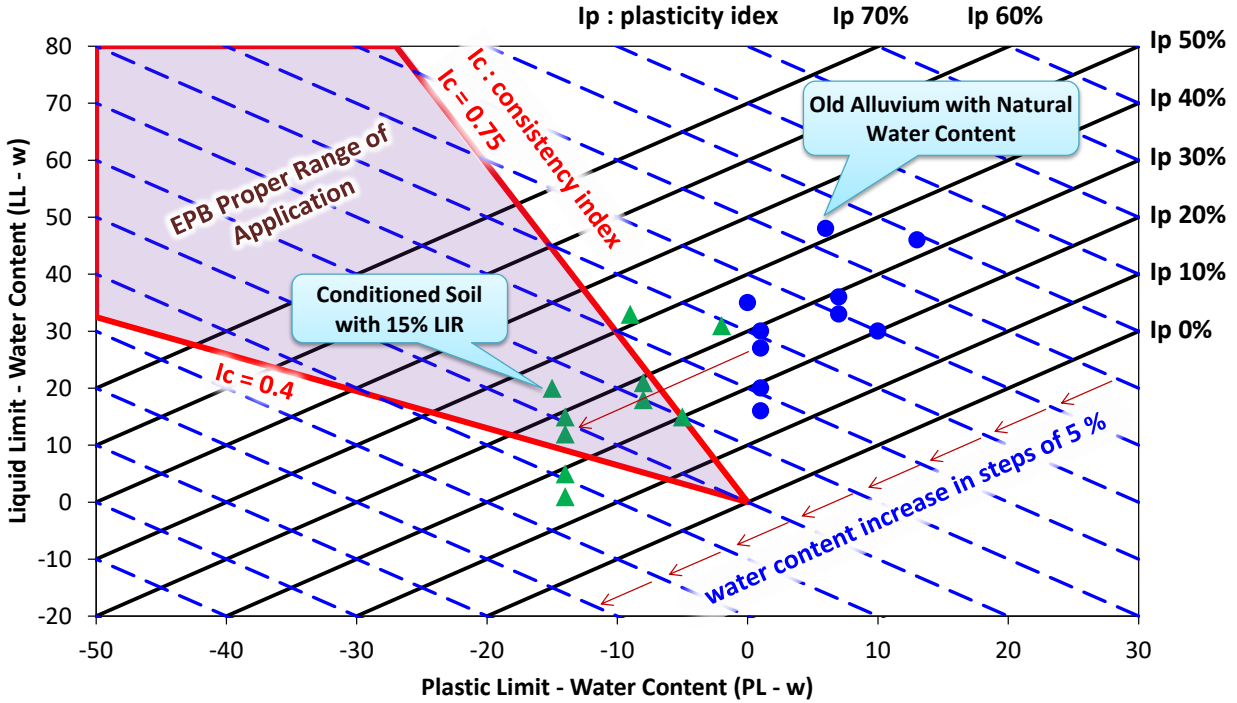
گل گرفتگی

* TBM clogging assessment (according to Thewes and Burger, 2005, 2010)



نمودار برآورد گل گرفتگی

* Need 10-30% additional liquid injection



According to Stefan Hollmann, 2014

آزمایشها

* According to Ic: 10-30% additional liquid injection
* Lab trial tests: 7.5-10% additional liquid injection

Injection Properties					Shear Strength (kPa)		
FER	FIR (%)	Con. (%)	WIR (%)	Max FIR (%)	Before test	After test	**LIR**
10	35	1	5	50	6.14	2.05	7.5
5	25	0.5	5	50	6.14	1.71	10

FER: Foam expansion ratio
FIR: Foam injection ratio
Con.: Concentration
WIR: Water injection ratio
LIR: Liquid injection ratio

آزمایش اسلامپ

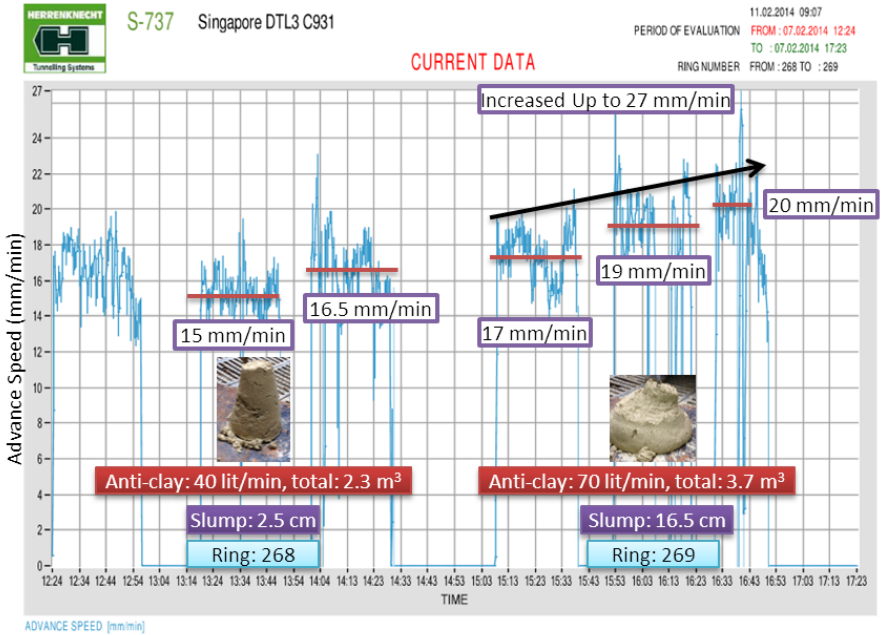
- Ring 260: on the muck from muck car
  - Very clumpy and sticky
  - Anti-clay injection: 40 lit/min
  - 5 cm slump

- Ring 261: on the muck from discharge point
  - Sticky
  - Anti-clay injection: 40 lit/min
  - 11 cm slump

- Ring 269: on the muck from discharge point
  - Low stickiness
  - Anti-clay injection: 70 lit/min
  - 16.5 cm slump

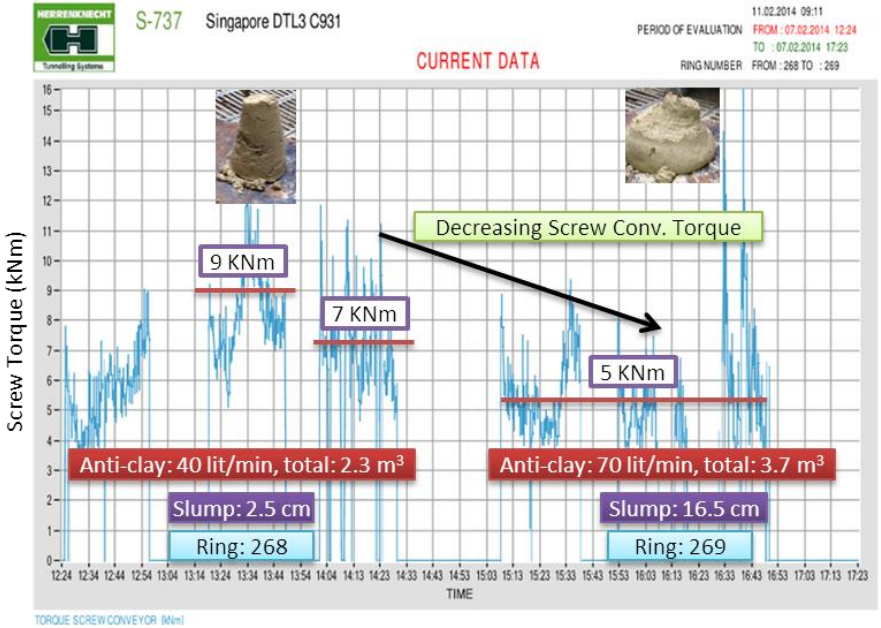
Homogeneous mud

اثر تغییرات تزریق پلیمر



Advance Speed (mm/min)

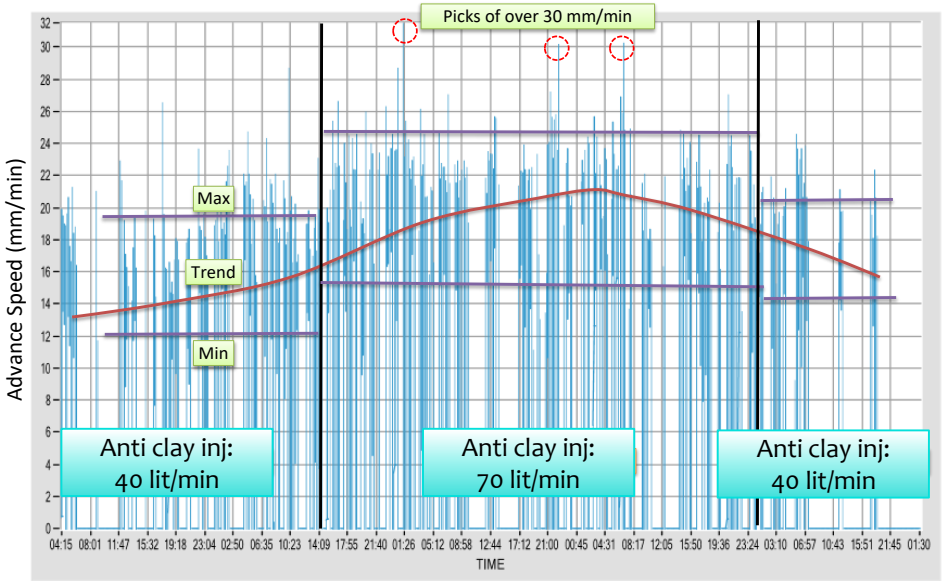
Increasing anti-clay injection caused an increase in penetration

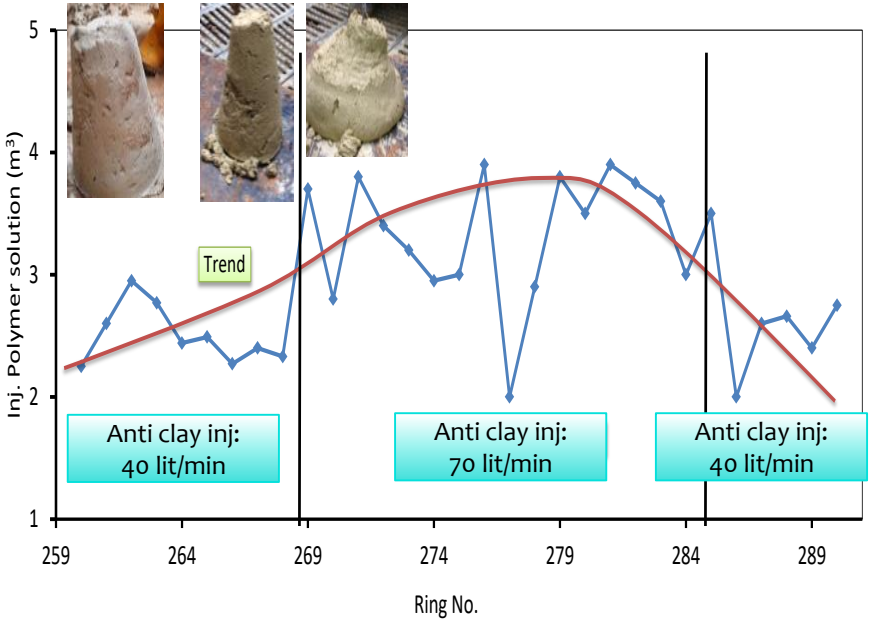


Screw Conv. Torque (KNm)

Increasing anti-clay injection caused a decrease in torque

اثر تغییرات تزریق پلیمر

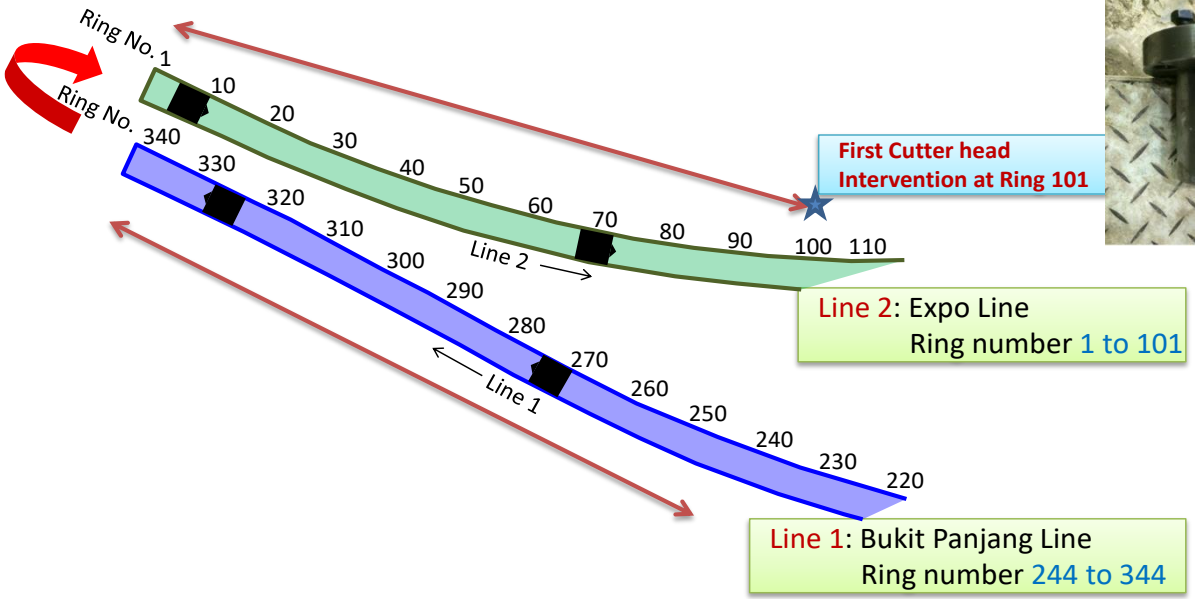




1. Increasing anti-clay injection caused an increase in penetration
2. There is a harmonic correlation between general trends of anti-clay injection rate and volume and penetration rate

سایش بالای ابزار حفاری

* Comparing TBM operational parameters for the same area of line 1 and 2
* NTNU SAT: “very high abrasive, SPT = 100



High abrasion on the ripper

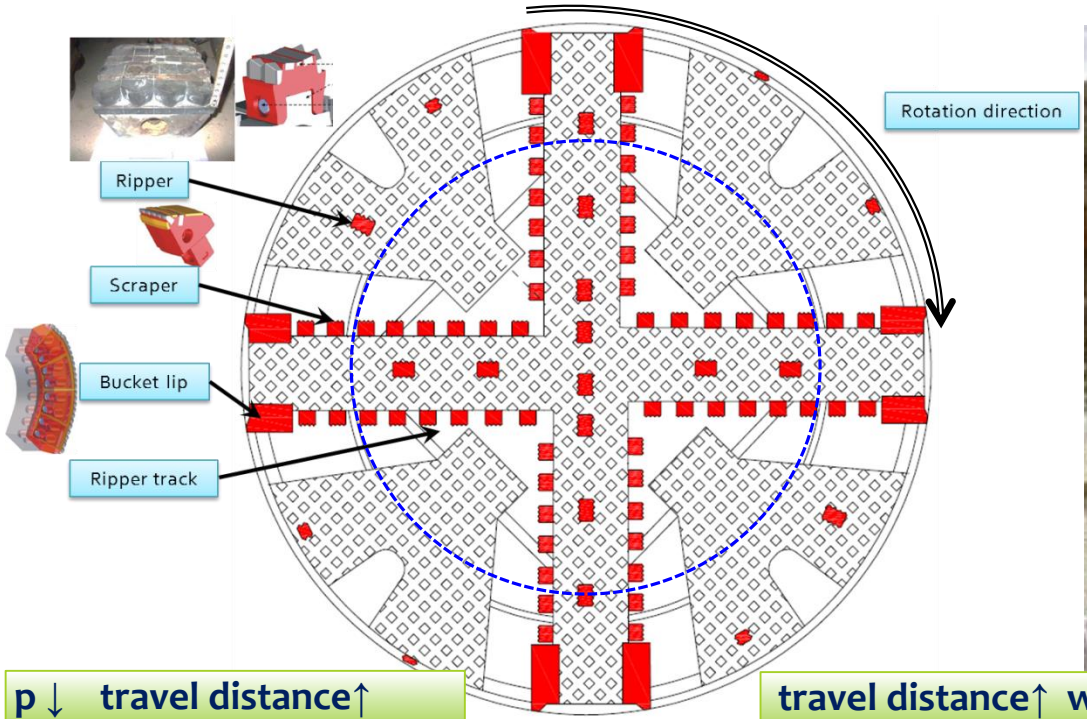
Broken wear detection sensor

Broken bucket lip

- Insufficient conditioning
- Abrasive soil
- penetration per revolution
- Higher rotation speed
- Low quality of cutting tools

فاکتورهای اساسی تاثیر گذار

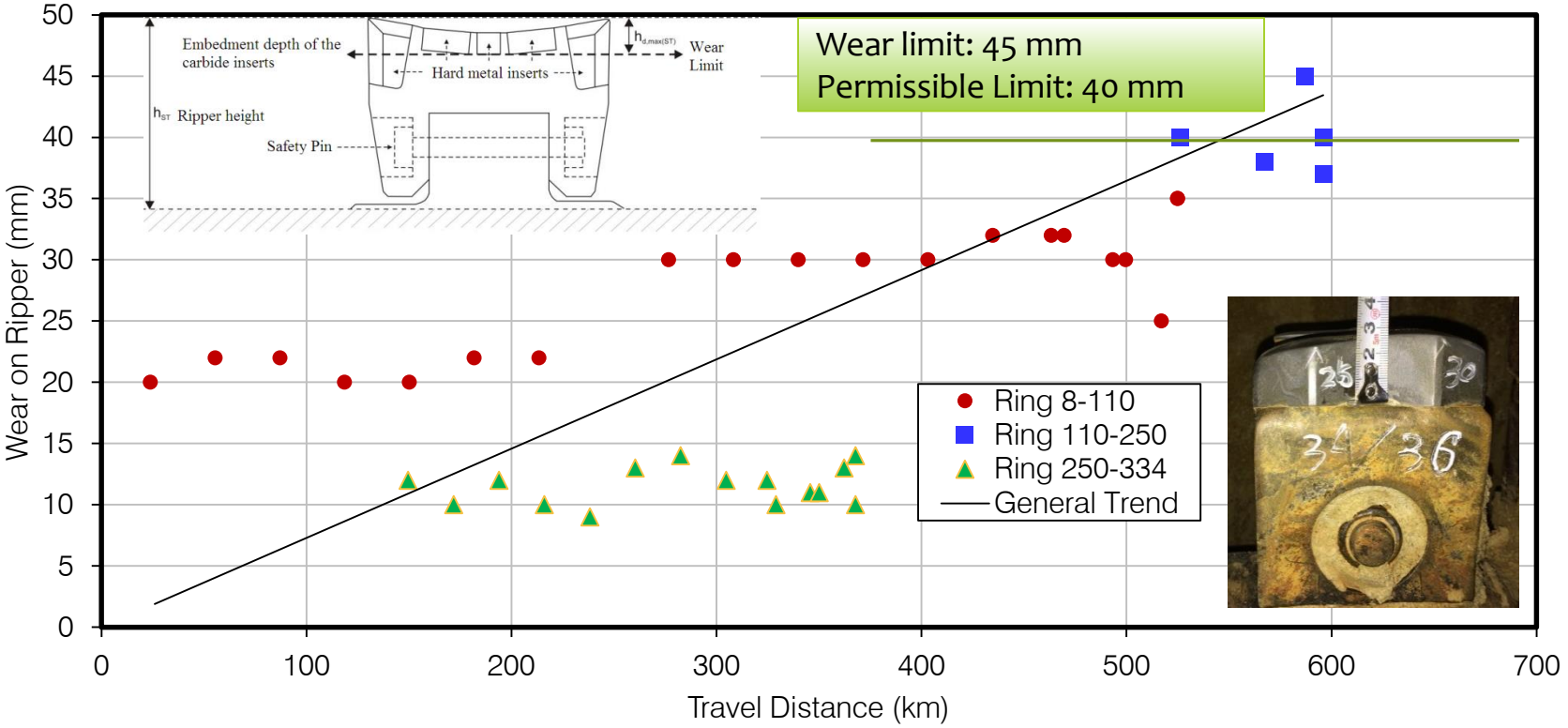
* Tool Wear depends on Tool Travel Length



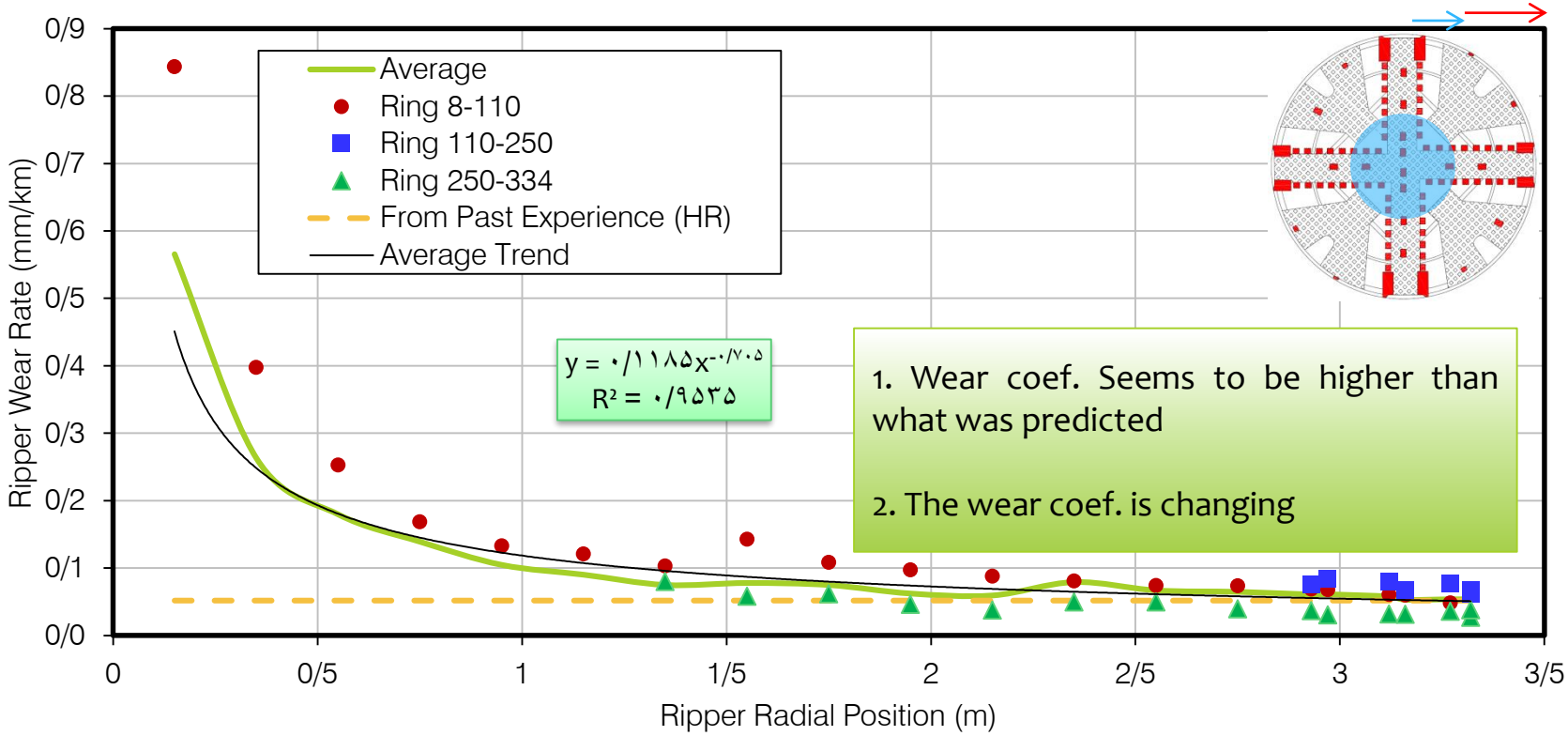
p ↓ travel distance↑

travel distance↑ wear ↑

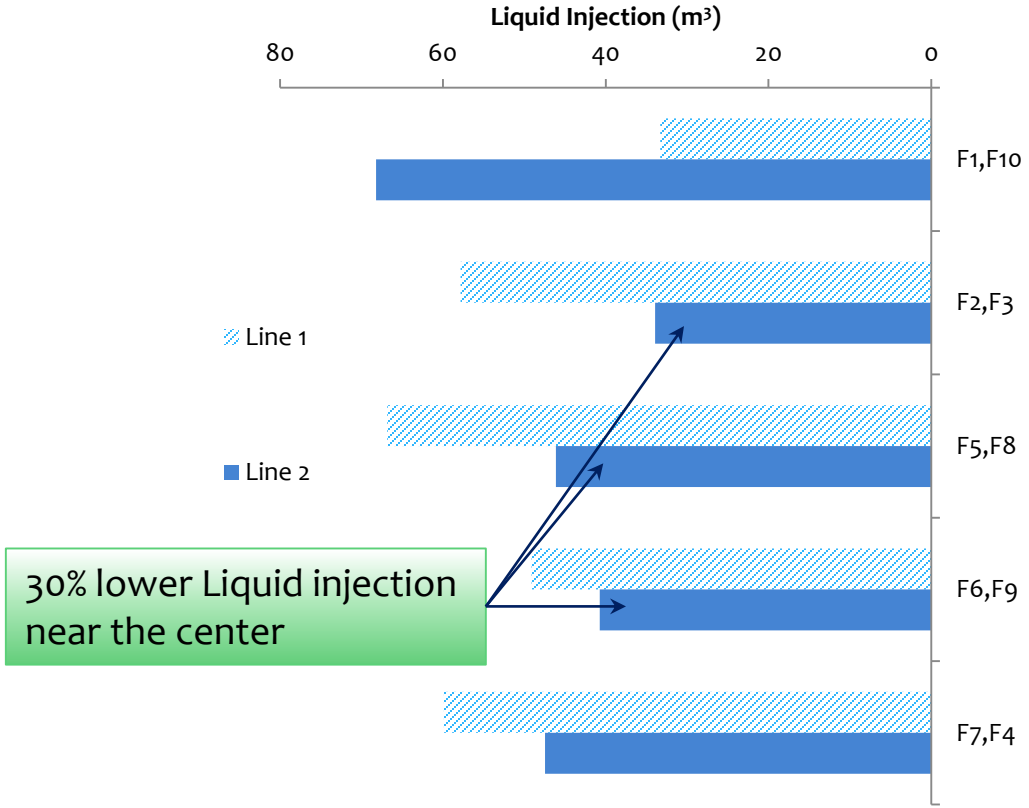
داده های سایش اندازه گیری شده



داده های سایش اندازه گیری شده

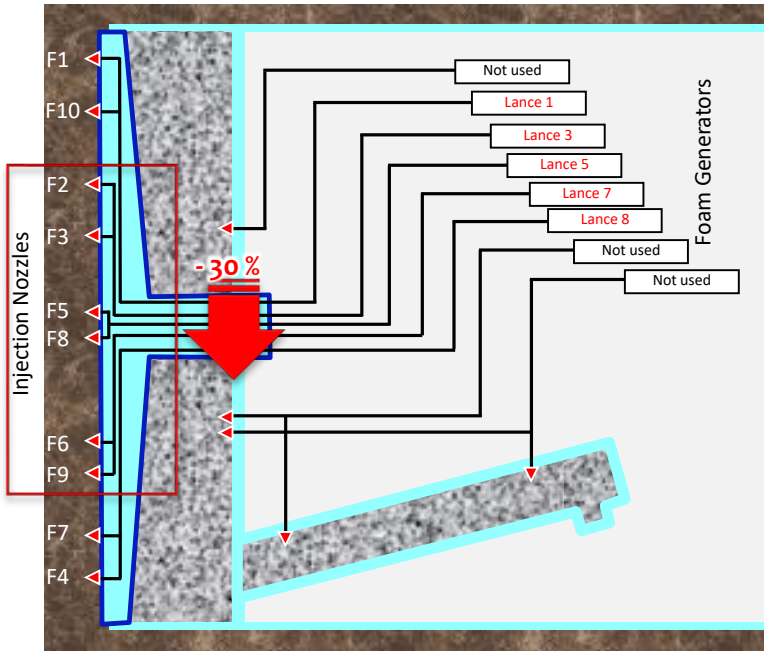


توزیع مقادیر مایع تزریق شده

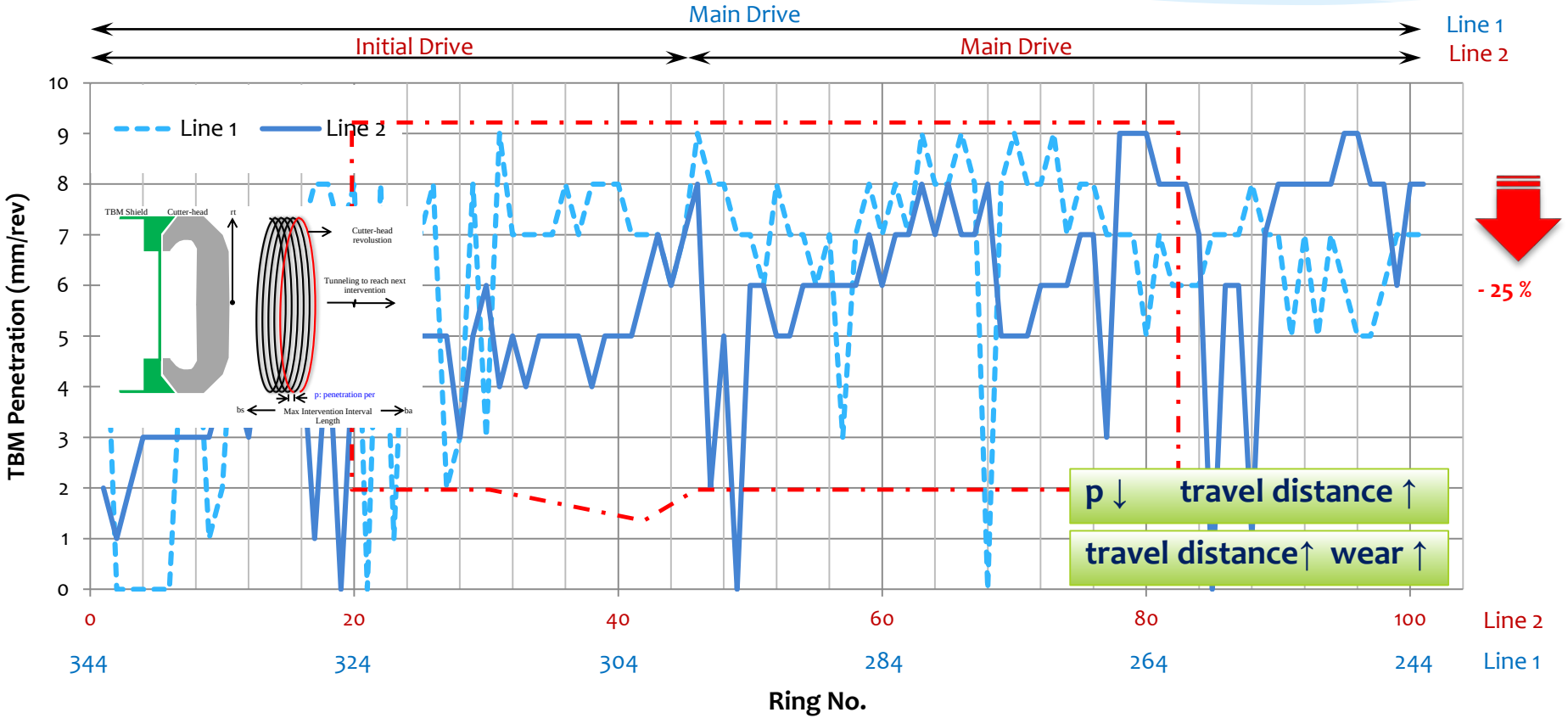


30% lower Liquid injection near the center

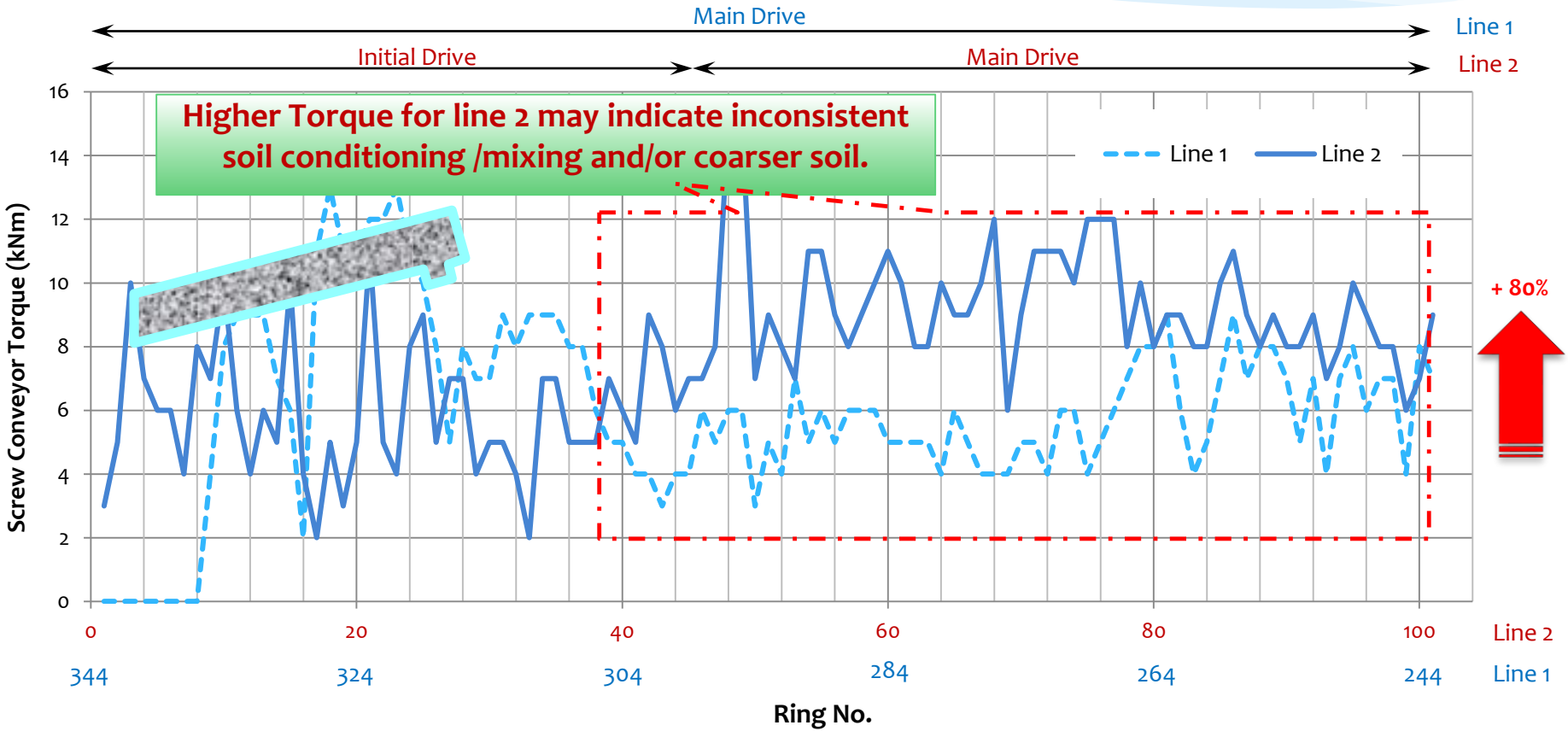
Cutterhead



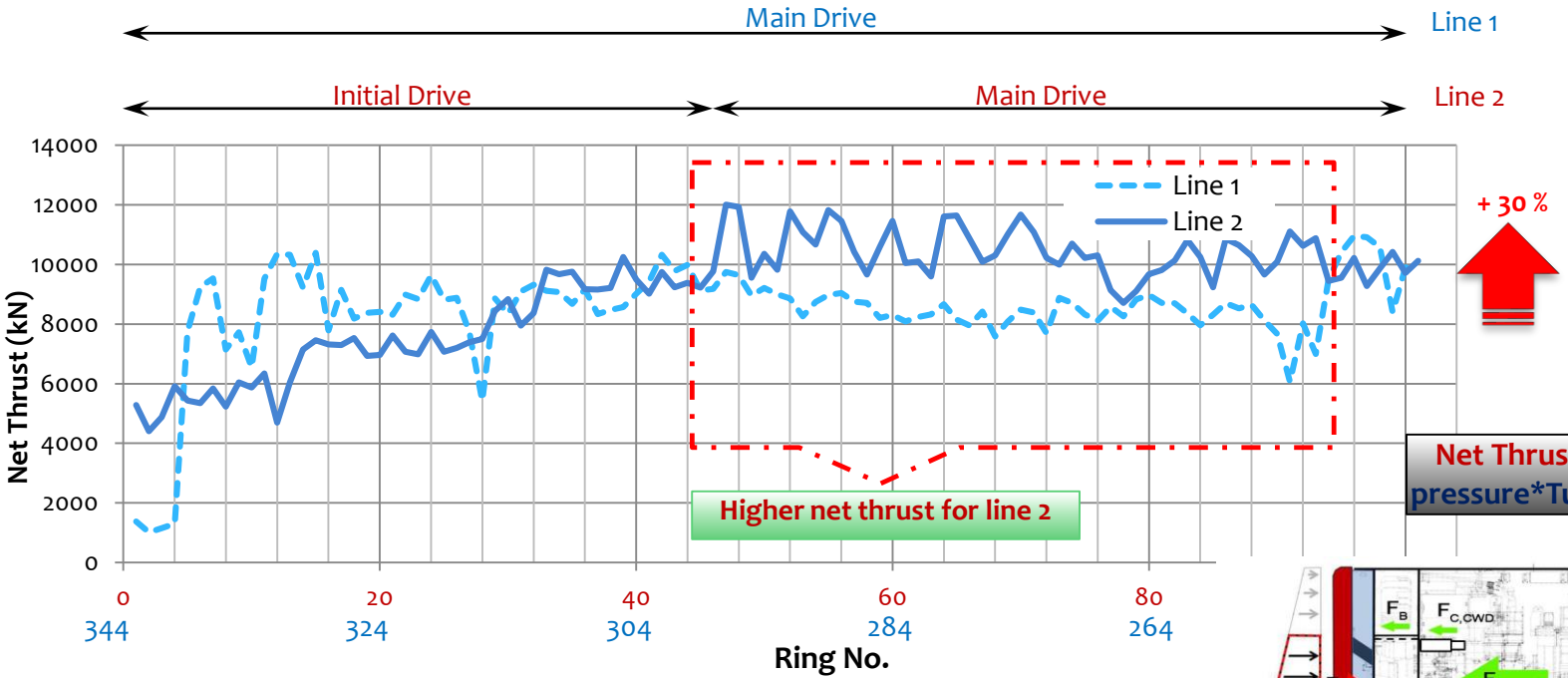
اثرپارامتر نرخ نفوذ



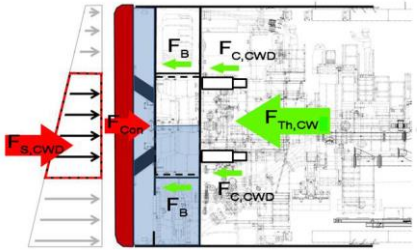
بررسی گشتاور نقاله حلزونی

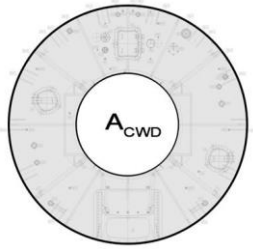


اثر پارامتر نیروی خالص محوری



Net Thrust = Total thrust - Earth pressure*Tunnel cross section area





According to Stefan Hollmann, 2014

با تشکر از حسن توجه شما