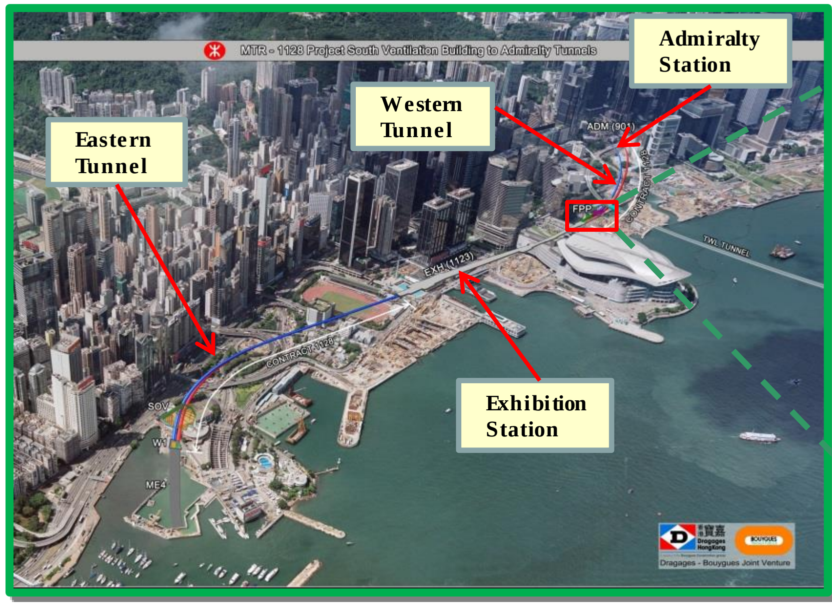
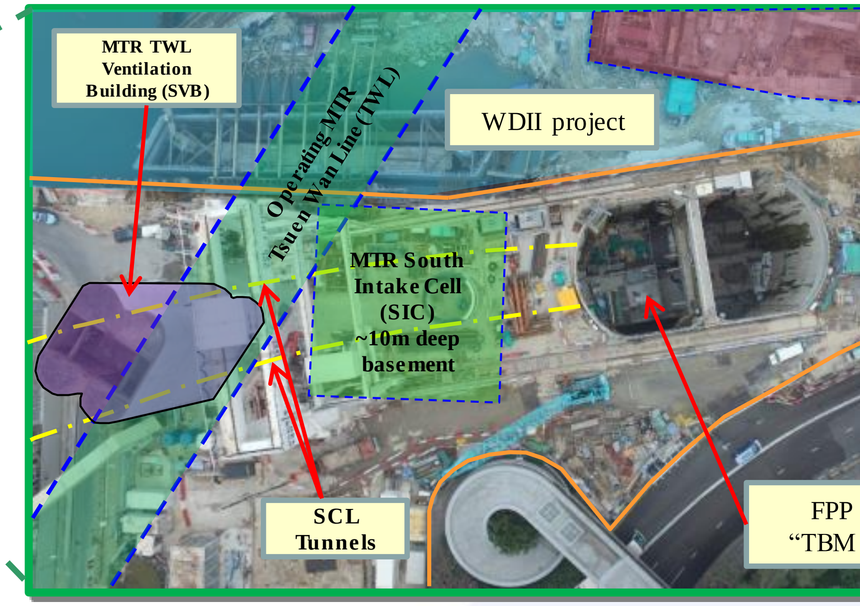
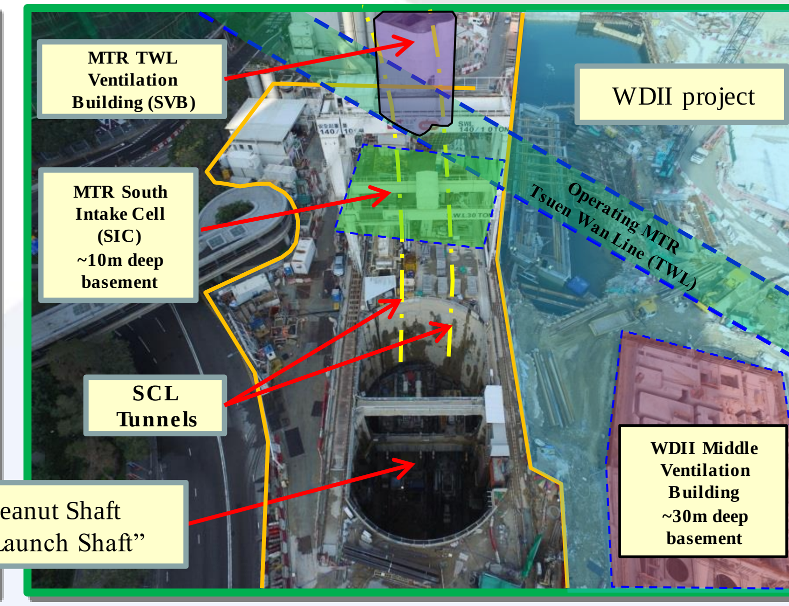
Temporary Works Excellence Award 2017

MTRC Contract 1128 SOV TO ADMIRALTY TUNNELS

Dragages - Bouygues Joint Venture







Project Background

The MTR Shatin to Central Link (SCL) - Contract 1128 South Ventilation Building to Admiralty Tunnels comprises the permanent works and the associated temporary works necessary for Tunnel Boring Machine (TBM) tunnels between South Ventilation Building (SOV) and Admiralty station, short sections of cut and cover tunnels near MTR Tsuen Wan Line South Ventilation Building (SVB) and Fenwick Pier Emergency Egress Point (FPP).

The key challenge of the project is to construct the Eastern Tunnels and Western Tunnels by Tunnel Boring Machine (TBM), as both tunnels go through the city's busiest districts. Meticulous project planning is essential in aiding the TBMs to navigate through a large volume of pile obstructions and utilities with zero interruption of services to citizens. To cope with the complex geological conditions, two different types of TBMs are being employed for excavation – a slurry TBM and an variable density TBM.

Contract No.	: **MTR Shatin to Central Link – (Contract 1128)**
Client	: **MTR Corporation**
Main Contractor	: **Dragages Bouygues Joint Venture (DBJV)**
Contract Sum	: **HK$ 5,227 M**
Total Tunnel length	: **2,328 m**

FPP Peanut Shaft for TBM Launching

A 40m deep shaft at Fenwick Pier is constructed for:

1. Launching TBM (2 times),
2. Construction of permanent Emergency Egress Point (EEP),
3. Construction of permanent Cut & Cover Tunnels (C&C) and connection with C&C tunnel sections to be built in Area 2 further east, afterwards,
4. Supply of Permanent Way of Railway such as 18m long rails and a 20m long Work Train before closing up of the opening in permanent structure.

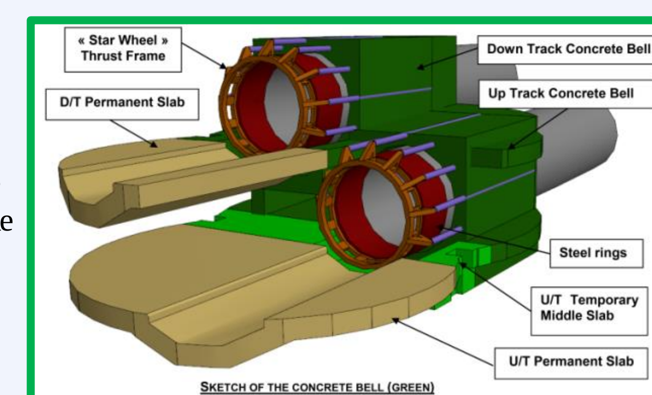
The shaft is constrained by the existing 10m deep MTR South Intake Cell (SIC) basement, the existing operating MTR Tsuen Wan Line (TWL), the existing old seawall, and the immediate adjacent contract WDII project.

Innovative Pre-stressed TBM Launching structure

To facilitate the TBM launching, a temporary launching structure is required to safely withstand and transmit the TBM thrust force to the surroundings.

Due to the limited space available in this project, an innovative pre-stressed TBM Launching structure was proposed.

TBM thrust force will first be transmitted to the starwheel thrust frame, and then to the concrete bell through Pre-stressing high tension steel bars. The force in the concrete bell will further be transferred to the RC collar / tympanum at the front and base slab at the back. The pre-stressing system provides an effective control to the movement induced by the TBM thrust force.



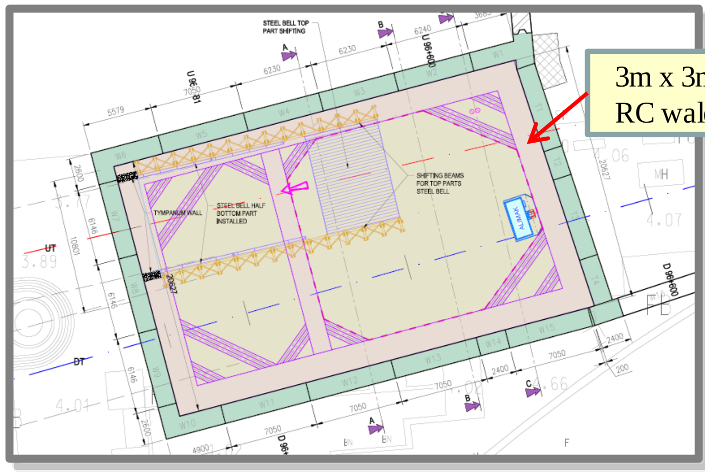
Design for Safety: FPP Peanut Shaft for TBM Launching

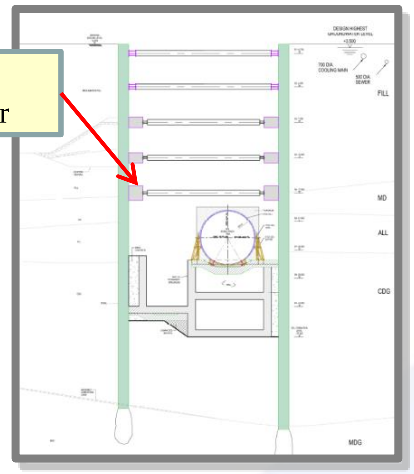
Peanut Shaped Diaphragm wall shaft

Instead of the planned rectangular shape traditional waler/strut shaft, an innovative twin-circular or "peanut" shape shaft is introduced to enhance the shaft overall stiffness to better control the ground and adjacent structure movement e.g. MTR TWL, footbridge and WDII deep basement and tunnel, etc; and provide a better programme, housekeeping, cost and safe construction method to the project. Critically, it creates an enlarged space unrestrained by typical de-propping constraints.

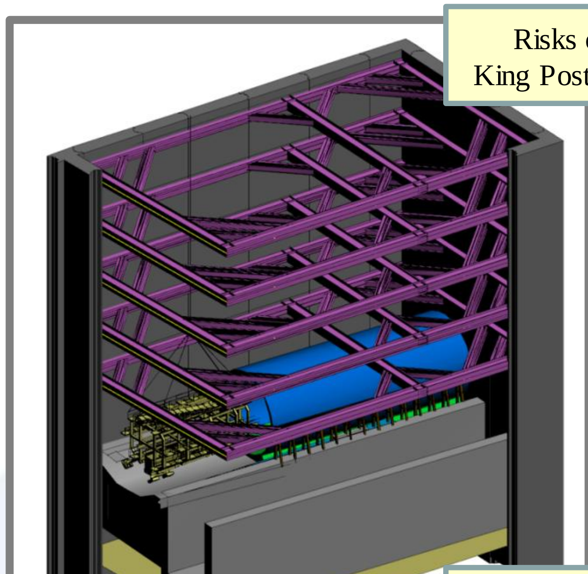
Traditional Rectangular Shaft (with steel struts)

Basic Information	
Dimension	35m x 24m
Strut	9 layers strutting with max. 3m x 3m size RC walers





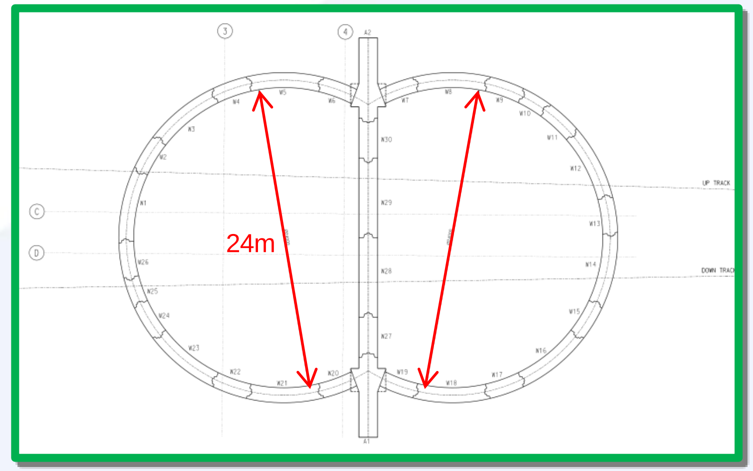
Identified Risks of Traditional Rectangular shaft	
1	**Heavy lifting within limited space** (due to massive struts and walers)
	- **Risk of collision** during frequent heavy lifting due to heavy blockage of sight

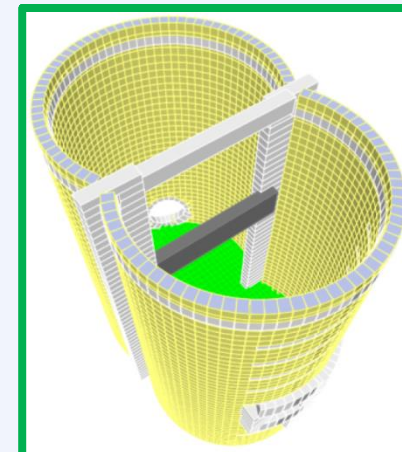



Heavy Lifting within limited space

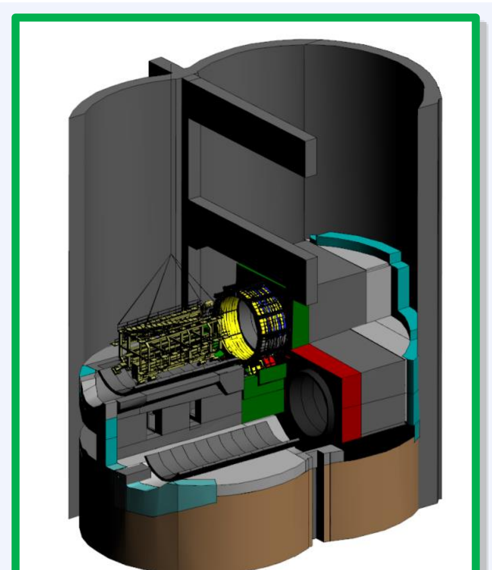
Alternative Peanut Shaft (strut-free)

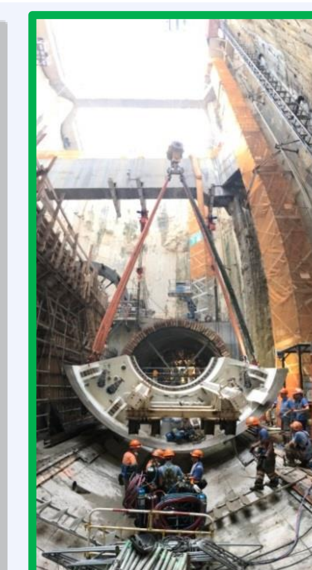
Basic Information	
Dimension	24m diameter twin circular shaft
Strut	2 middle cross beams only





How the Peanut shaft eliminated the risks of temporary work	
1	**Strut-free shaft (Saving ~2,000 Ton of steel work)**
	- Minimize inherent risks of heavy lifting in narrow space





Strut-free shaft

Design for Safety: FPP Peanut Shaft for TBM Launching

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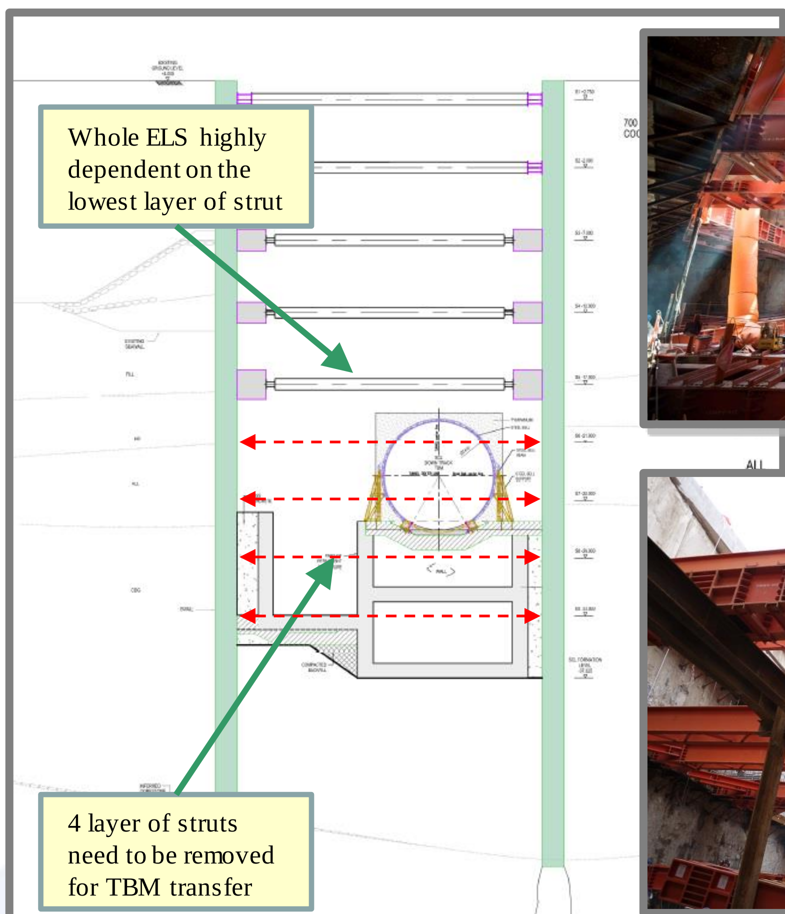
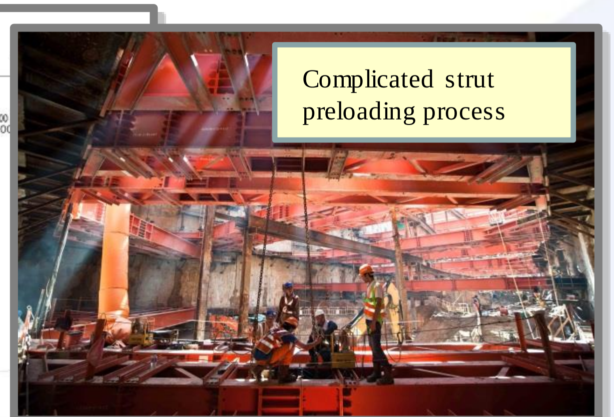
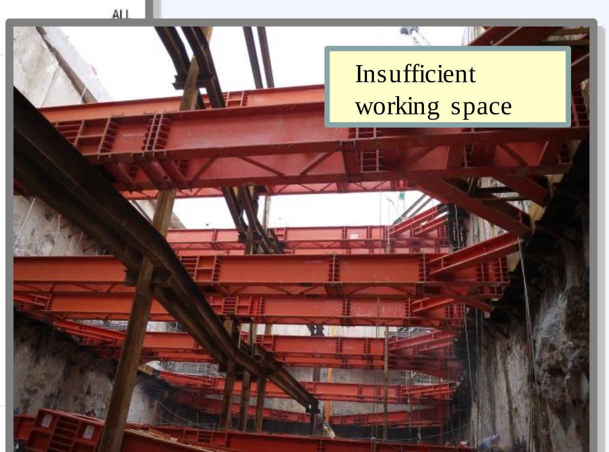
Traditional Rectangular Shaft (with steel struts)

Identified Risks of Traditional Rectangular shaft	
2	**Complicated ELS work sequence**
	- Owing to two different levels of tunnels, 4 layers of struts needed to be removed for TBM assembly /transfer
	- Permanent structure needed to be constructed to compensate the strut removal
	- Complicated strut preloading process.
	- High risk was anticipated due to frequent interface works
3	**Low redundancy of ELS capacity**
	- The whole ELS will be highly dependent on the lowest layer of strut
	- Risk of overall failure of ELS due to unexpected working quality / incident
4	**Insufficient space for storage of backup gantries on surface**
5	**Large ground settlement up to ~100mm**

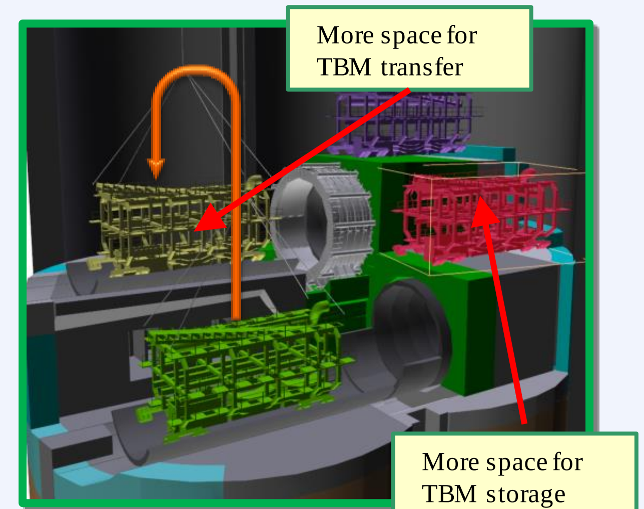


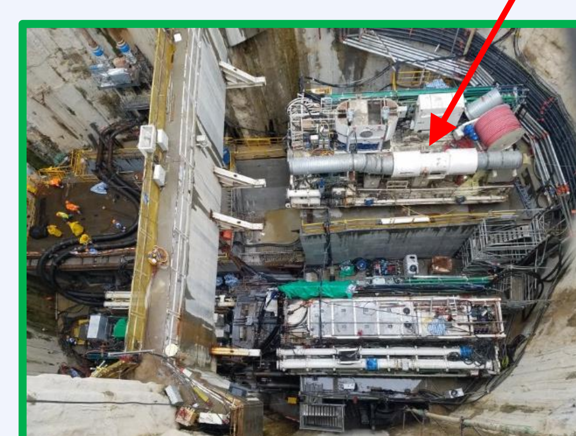




Alternative Peanut Shaft (strut-free)

How the Peanut shaft eliminated the risks of temporary work	
2	**Simple ELS work sequence**
	- No interface risk between strut installation and bulk excavation
	- No interface risk between permanent work construction, strut removal work and TBM assembly / transfer.
	- Time saved on excavation, which allows more time and better preparation for temporary work construction for TBM launching
3	**Clear load path via circular hoop force** in diaphragm wall that increases the redundancy of the ELS system
4	**More working space for TBM backup gantry storage inside the shaft**
5	**Ground settlement has been reduced to ~40mm (~60% reduction)**





Selection of structural form: Innovative TBM Launching Structure

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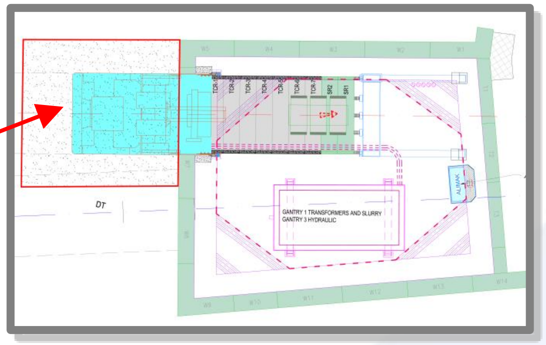
Innovative Pre-stressed TBM Launching structure

Innovative TBM launching frame and break-in (breaking into the ground) method was introduced. Instead of typical ground treatment outside the Diaphragm Wall (D-wall) at the break-in zone of TBM, a combination of a concrete and steel bell pressurized chamber is designed to allow TBM to be pressurized to design level, balancing the soil and water pressure outside, before the TBM breaks into the ground. In addition, an innovative pre-stressed structure (starwheel) was designed to replace traditional heavy thrust frame, which has provided better housekeeping and more room for TBM assembly and daily operation.

External Grout block for TBM Break-in (Conforming)

Identified Risks of External Grout block for TBM Break-in	
1	**Potential settlement of surrounding structure adjacent to the Shaft**
	- Jet grouting work will create high safety risk of settlement in surrounding structure
2	**Located adjacent to the sea . Expected with old seawall and boulders**
	- Quality of Jet Grouting cannot be assured in seawall zone (grout leakage)
	- Potential loss of confinement during TBM launching due to unassured grout quality

Quality of Jet grouting outside the shaft cannot be assured in seawall zone

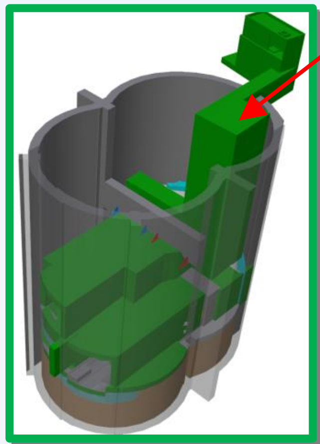


Full Steel Bell Option

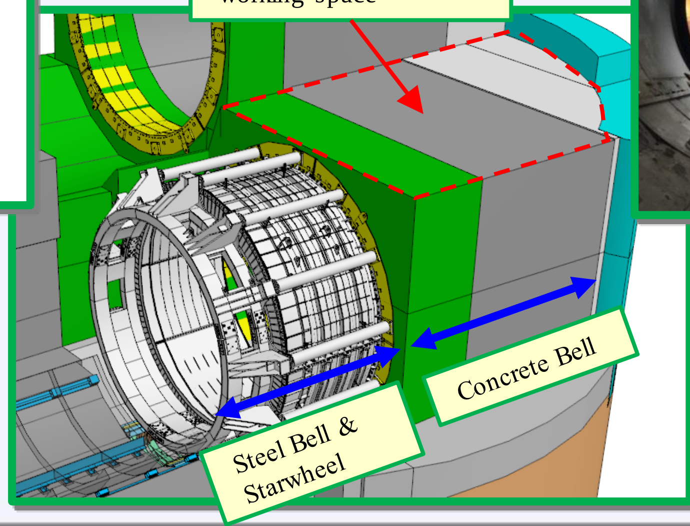
Identified Risks of Full Steel Bell Option	
1	**High risk for dismantlement of Steel Bell**
	- High risk of dismantling 10m long large steelwork from a constructed Tunnel
	- Need to construct C&C tunnel afterward with limited space in shaft

Concrete Bell with light duty Steel Bell & Starwheel

How Concrete Bell minimizes the risks of temporary work	
1	**No Jet grouting required in seawall zone outside the Peanut Shaft**
	- TBM confinement can be assured
2	**Concrete bell itself can be utilized as permanent structure. Therefore,**
	- Permanent work (Emergency staircase) above the concrete bell can be constructed **at the same time with TBM operation underneath**
	- In case any delay in TBM operation, it will not increase the interfacing work
	- **Shorter and lighter steel structure** thanks to the use of permanent structure that was partially constructed
	- **Minimize risks associated with steel bell dismantling** by reducing the length of steel bell from 10m to 3.3m
3	**The roof of the concrete bell can allow more storage space for TBM back-up gantry during TBM launching, thus provide a safer working environment.**



Permanent work (staircase) above can be delinked from tunneling work



Can utilize the concrete bell roof for extra working space

Selection of structural form: Innovative TBM Launching Structure

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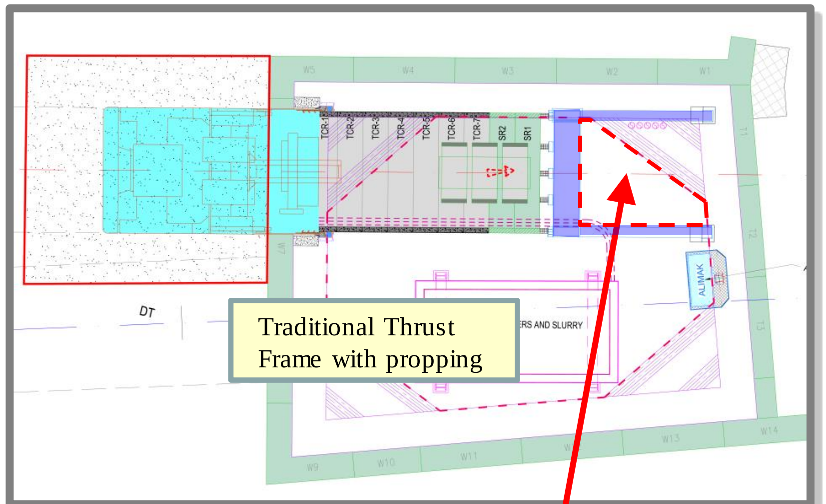
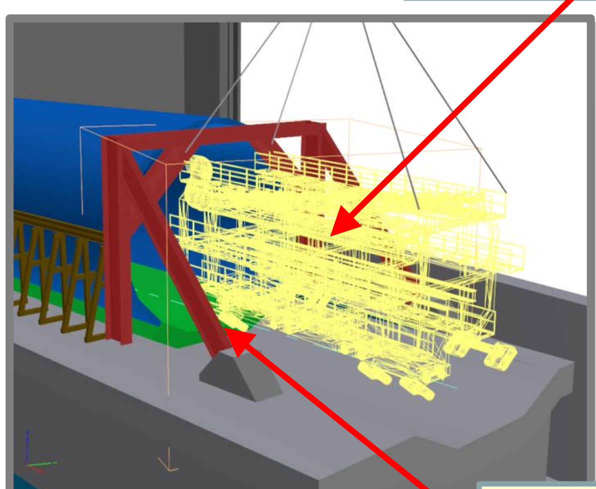
Traditional Thrust Frame (with Propping at the back)

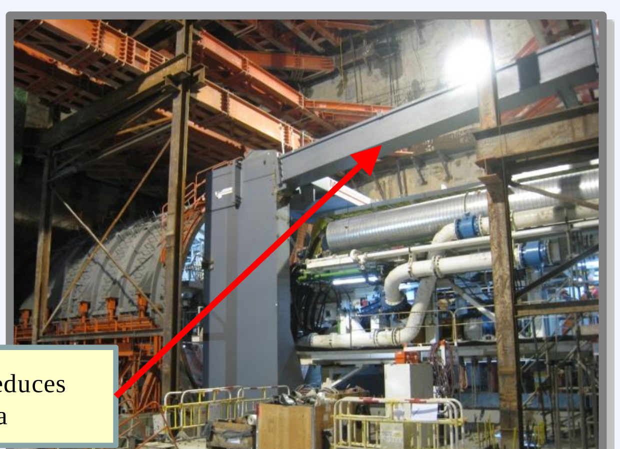
Identified Risks of Traditional Thrust Frame	
1	**Propping system – Reduce lifting and working space** - In order to resist the TBM thrust force, a large scale propping system will be required which will greatly reduce the working space
2	**Heavy Lifting** - Heavy duty steel structure (100+ Ton) will create risk of lifting



Reduced working area for gantry installation

Heavy Lifting (100+ Ton)

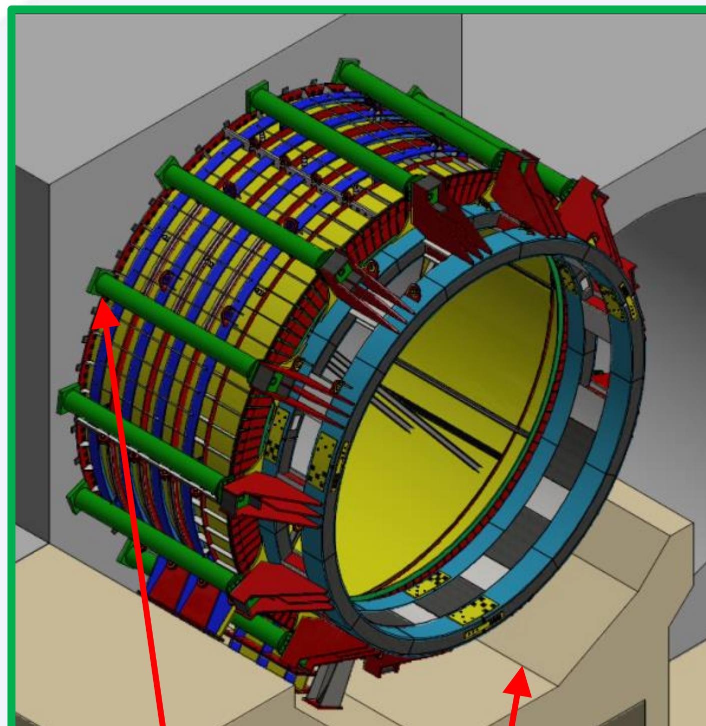


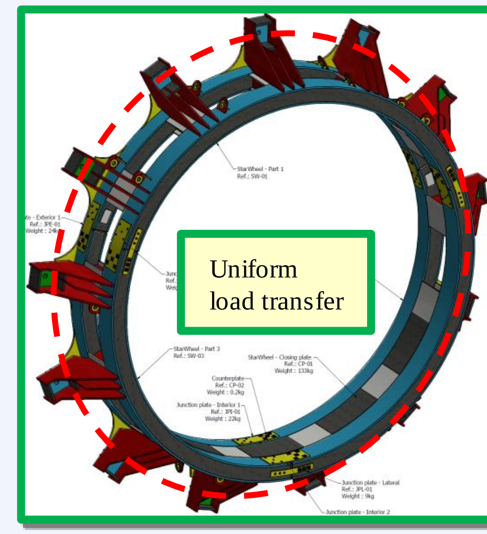


Steel prop reduces working area

Alternative Starwheel (with Pre-stressed bars in front)

How Starwheel minimizes the risks of temporary work	
1	**"Starwheel with Pre-stressed Bar" Thrust Frame system** - Anchored to the concrete bell through high tension pre-stressed bars - **Much lighter steelwork** (~30T) and **safer structure** as TBM thrust force can be transferred uniformly around the circumference of the starwheel by pre-stressed bars - **Provide more working area** for TBM assembly work at the back
2	**Pre-stressing system to control the potential displacement due to TBM thrust** - The starwheel is pre-stressed and connected to the concrete bell. Therefore, the displacement of the starwheel due to TBM thrust force will be much smaller and under control.





Pre-stressed and connected to the concrete bell

Much more working area at the back

Better Interface between Permanent and Temporary works

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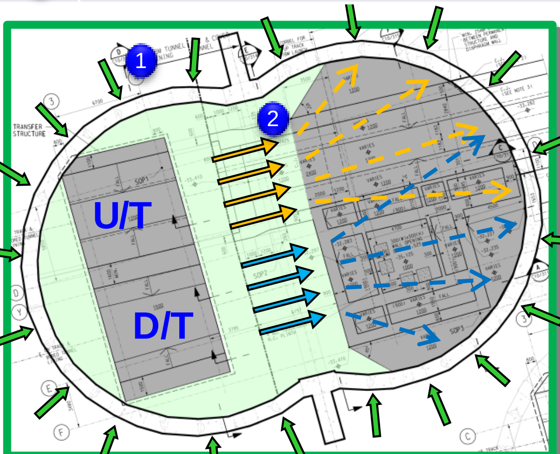
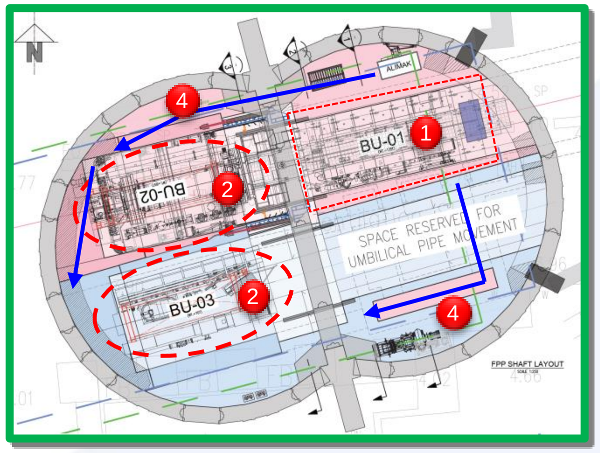
Comprehensive consideration in planning stage

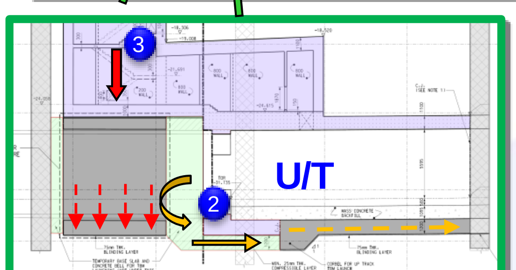
In order to facilitate both the permanent and temporary structure to achieve the permanent functions of the Emergency Egress Point and temporary work construction such as TBM launching, comprehensive considerations have been made before finalizing the layout.

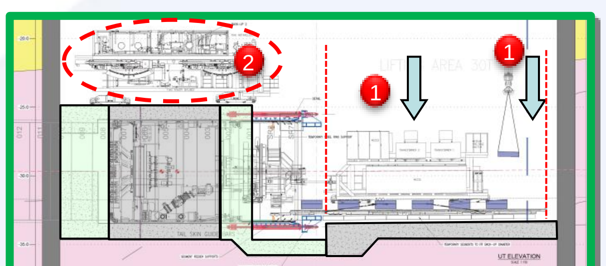
Loading considerations (Both Permanent & Temporary)	
1	**Permanent & temporary base slab to cater for the propping force of the ELS**
2	**Permanent & temporary structure to cater for the TBM thrust load**
3	**Permanent loading from the staircase structure above**

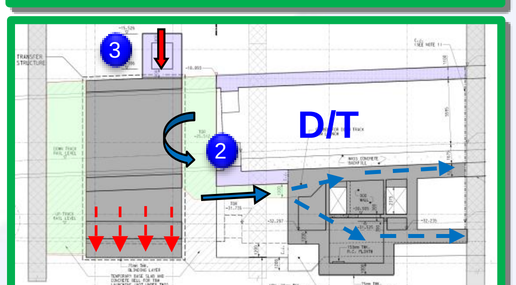
Construction space considerations	
1	**Adequate space for TBM assembly & segment delivery**
2	**Adequate space for TBM backup gantry storage for launching**
3	**Adequate space for reserved opening for P-way delivery**
4	**Adequate space for workers access and safe working platform**







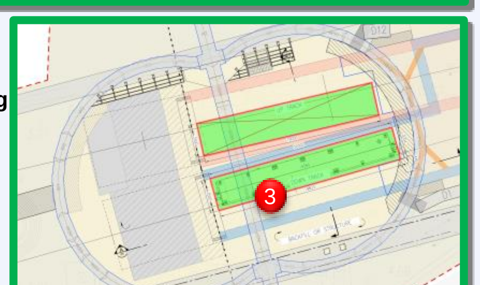




1st stage perm. work before TBM launching

Temporary work

2nd stage perm. work after TBM launching



Relocate the Permanent Escape route and Emergency Staircase

After comprehensive considerations in the planning stage, DBJV has proposed the following changes in permanent structure, not only to improve the working environment in construction stages, but also to enhance the interface between different scopes of permanent work construction.

Relocate the Permanent Evacuation walkway

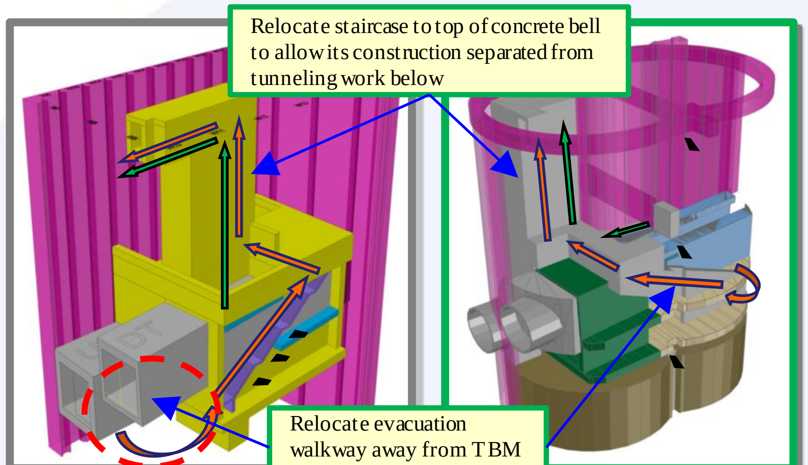
Conforming scheme: The Evacuation walkway of Uptrack tunnel (lower tunnel) is located next to the TBM break-in position. This arrangement will affect the TBM launching (next to the pressurized chamber) and thus requires a late cast of this structure.

DBJV revised scheme: The Evacuation walkway is relocated to the backward side, which allows its construction to be done prior to TBM launching, and provides a proper access to the Downtrack area.

Relocate the Permanent Staircase on top of the Uptrack Concrete Bell

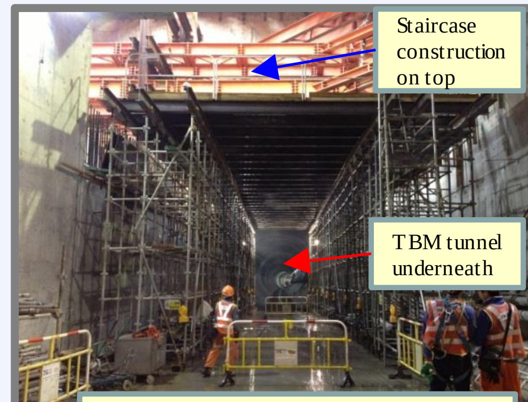
Conforming scheme: The Permanent Staircase is located in the middle of the shaft. It implied that a complicated interface would occur between TBM tunneling work and Staircase construction.

DBJV revised scheme: The Permanent Staircase is relocated and situated on top of the Uptrack Concrete Bell, which allows clear separation between permanent and temporary work construction.

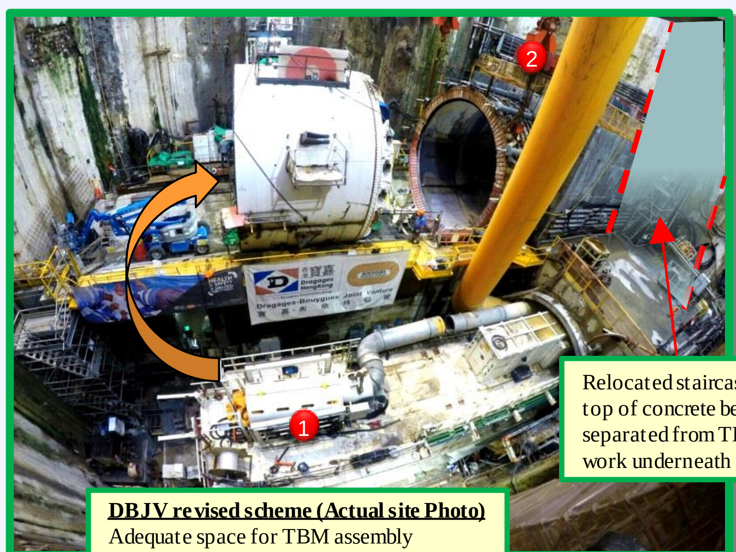


Conforming scheme

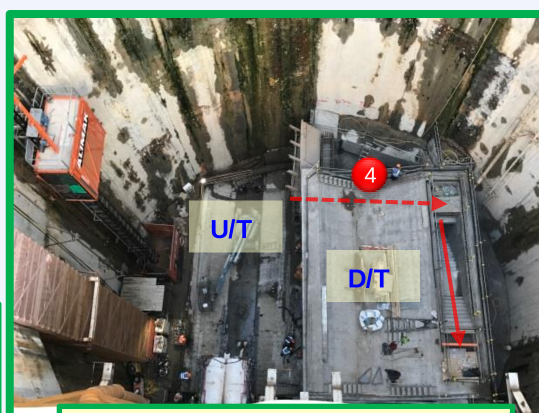
DBJV revised scheme



Conforming scheme (Photo for example)
Complicated interface between TBM tunneling work & Permanent work above



DBJV revised scheme (Actual site Photo)
Adequate space for TBM assembly
Relocated staircase on top of concrete bell



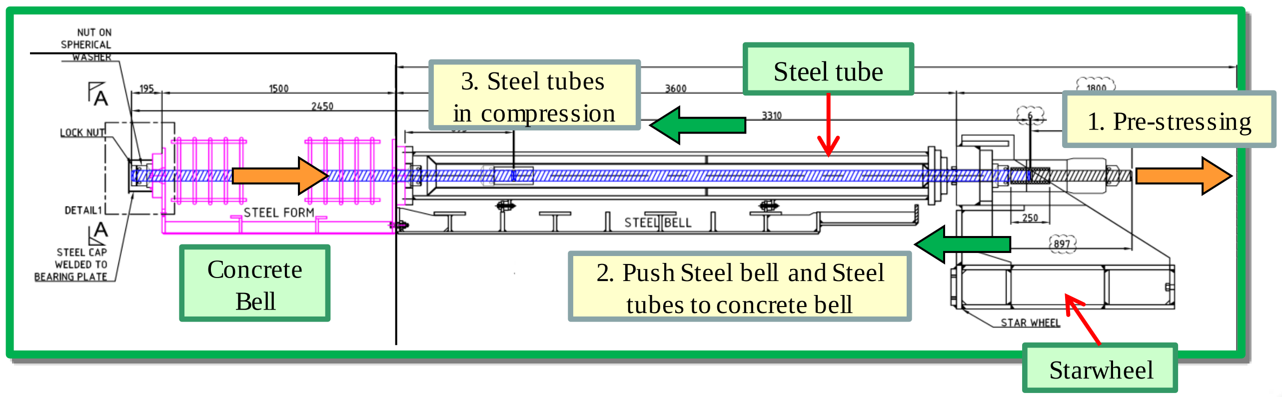
DBJV revised scheme (Actual site Photo)
Relocated Evacuation walkway to act as proper temporary access (from U/T to D/T) as well

Safer Dismantling procedure

Dismantling of Starwheel and Pre-stressed bars

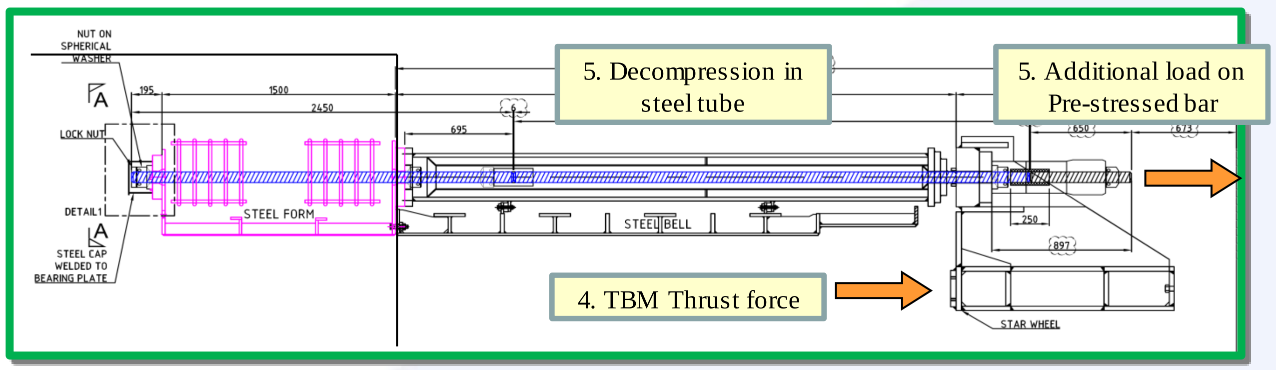
Principle of the Pre-stressed Starwheel system

1. Pre-stress the high tension steel bars which are anchored in the concrete bell
2. The pre-stressed bars will push the starwheel toward the concrete bell with pre-installed steel tubes in between.
3. After achieving the target pre-stressing load, the end of the pre-stressed bars will be locked in the starwheel. The steel tubes will also have locked-in compression.



4. When the TBM thrust load starts to push the Starwheel, the pre-stressed bar will be elongated.
5. It will induce additional load on the pre-stressed bars and decompression on the steel tubes.

TBM Thrust force → Pre-stressed bars elongation
→ Tubes decompression & Additional load on the Pre-stressed bars



In order to safely dismantle the starwheel and its pre-stressing bars, the following matters needed to be assured:

1. **No more TBM thrust load is transmitted to the Starwheel**
   To ensure TBM thrust load is transmitted to the hardened segment annulus grouting with surrounding ground after a certain distance of tunnel excavation. Dismantleing of starwheel will therefore not affect the TBM operation and tunnel lining stability.
2. **Identify the residual tension remained in the pre-stressed bars**
   To ensure no overloading of the pre-stressed bars will occur during de-compression.

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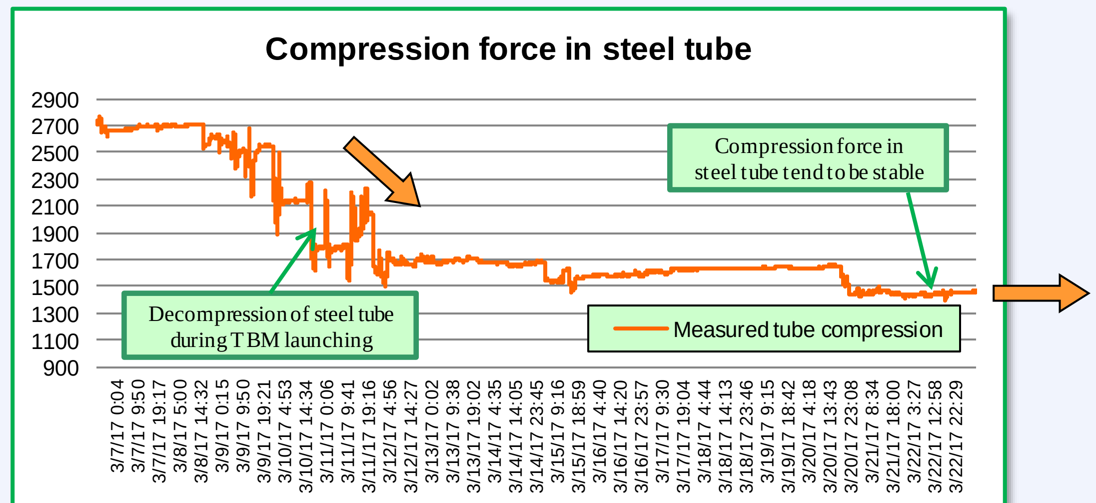
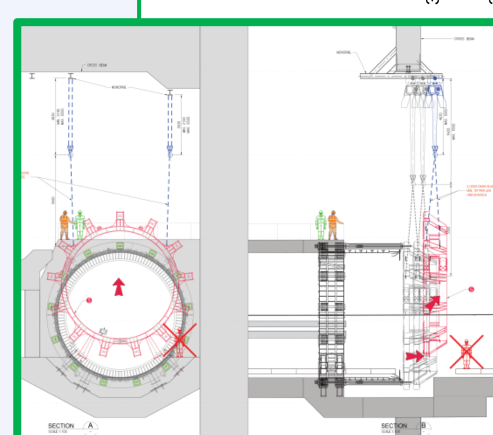
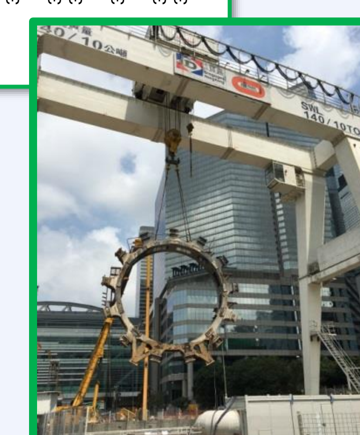
Measures have been carried out for safe dismantling

1	**TBM thrust load was limited during launching** to avoid overloading on the pre-stressed bars and full decompression of the tubes
2	**Strain gauges were installed** to monitor the change in stress (decompression) in tubes during TBM launching stage, and thus monitor the additional load on the pre-stressed bars.
3	**Once the measurement indicated that the stress in steel tubes were not affected by the TBM thrust load anymore:**
	- The starwheel and pre-stressed bar can be dismantled without affecting the tunnel lining stability
	- The final lock-in stress in the prestressed bar was identified, and safe working load can be calculated for de-stressing the bars.
4	**Simplified Method Statement** has been prepared in consultation with the frontline staff to agree on the detailed procedure and potential risk of de-stressing the pre-stressed bars and dismantling the starwheel.





Sample of Simplified Method Statement for Starwheel Dismantling



Dismantling of Starwheel

Real-time Automatic Monitoring system of the temporary works

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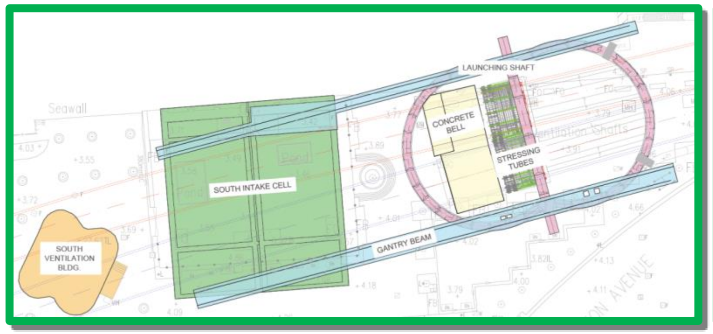
Background

In view of the existing buildings, structures, services, etc. in the vicinity of our Peanut shaft and pre-stressed launching structure, extensive instrumentation and monitoring works have been carefully planned to be implemented in order to monitor the effects of construction works at various stages, such as shaft excavation & TBM launching, etc.

Instrumentations for permanent and temporary works

Geotechnical monitoring : Settlement monitoring points, piezometer, etc.
Structural monitoring : Real-time Automatic Deformation Monitoring System (ADMS), strain gauges, inclinometer, etc.



Layout of monitoring coverage

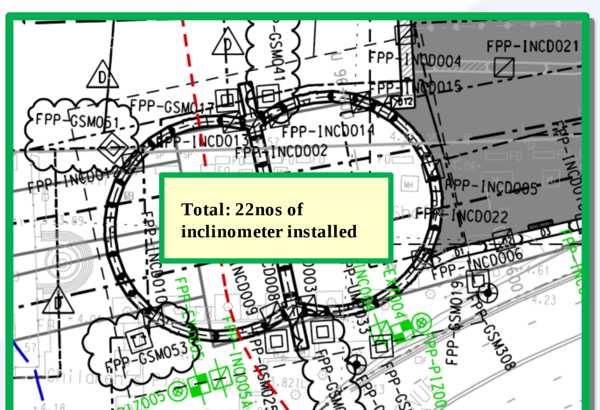
Motorized Total Station

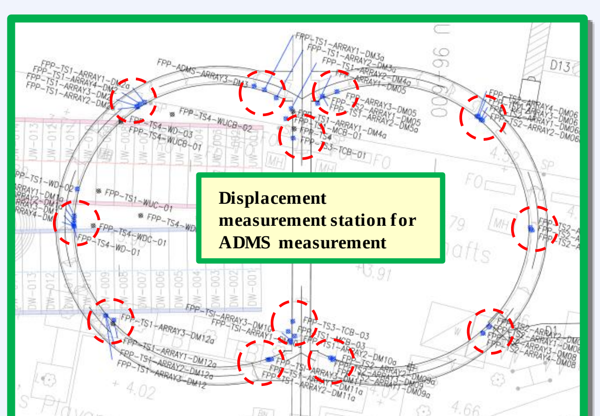
ADMS prism

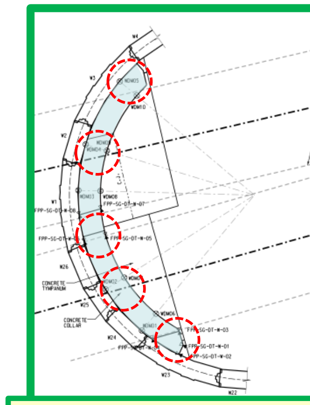
Example 1 (Peanut Shaft Diaphragm wall & Concrete Bell)

Instrumentation and monitoring were implemented in diaphragm wall, cross beam and concrete collar at D-wall opening, etc to monitor the effects of bulk excavation and TBM launching to the temporary structure. Information obtained from monitoring will be used for verification of geotechnical design and compared with predicted performance. Scope of instrumentations will include:

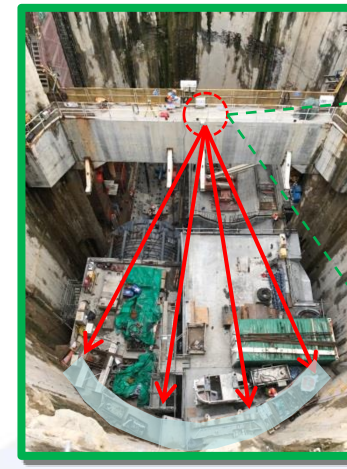
- Groundwater monitoring point equipped with piezometers and standpipes.
- **Inclinometers for shaft excavation**
  – to monitor the lateral movement of the ground at different depths, in particular in areas where there is deep foundation in close proximity to excavation works.
- **ADMS for TBM launching**
  – to real time monitor the movement induced in diaphragm wall and concrete collar

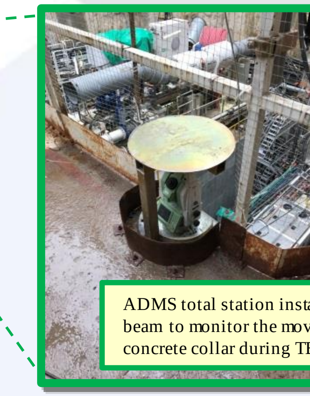






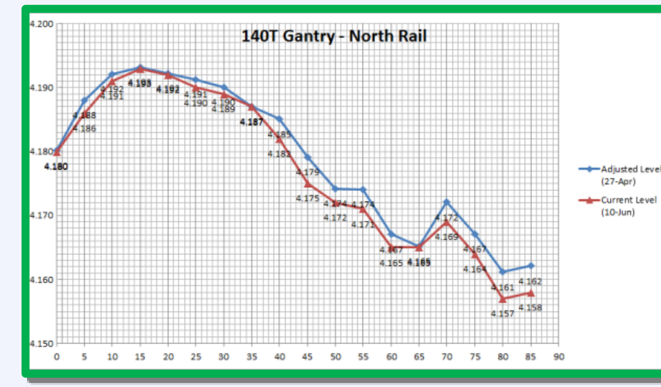
ADMS displacement measurement station installed on the Concrete Collar at D-wall opening for TBM launching





Example 2 (140T Gantry Crane)

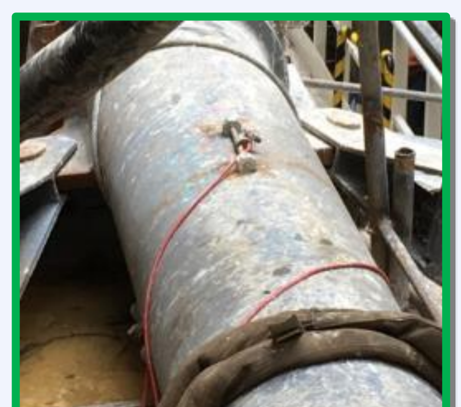
Regular monitoring of 140T Gantry crane footing is carried out to ensure the level is within the tolerance specified by the crane manufacturer. Adjustment of rail level has been made when the level was found to be out of tolerance.



Monitoring of 140T Gantry Crane Rail and Beam

Example 3 (Starwheel pre-stressing system)

Regular monitoring of pre-stressed bar and tube system to ensure no over-stressing occurs in the pre-stressed bar during TBM launching. It is found that the loading in the pre-stressed bar and tube is in line with our design.



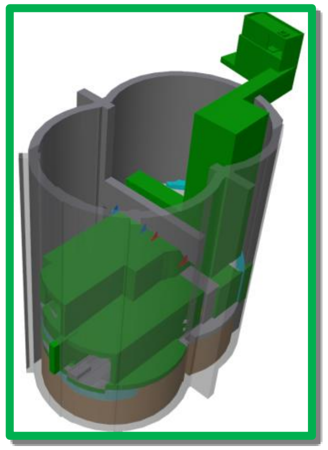
Strain gauges installed on 4 tubes to measure their decompression
- 3 gauges per tube - 120° spacing
- Data acquisition every 30sec with Geoscope
- Cross analysis with TBM thrust load

Full implementation of BIM and 3D drafting technique

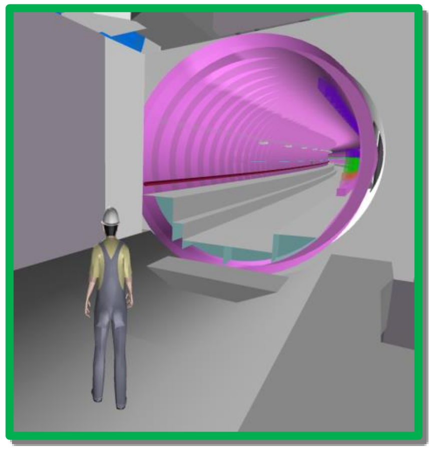
Background

In 1128 project, Building Information Modeling (BIM) models for permanent structure are developed based on the 2D working drawings from our Client. Major elements of our BIM model included Architectural model, Civil and Structural model and MEP model.

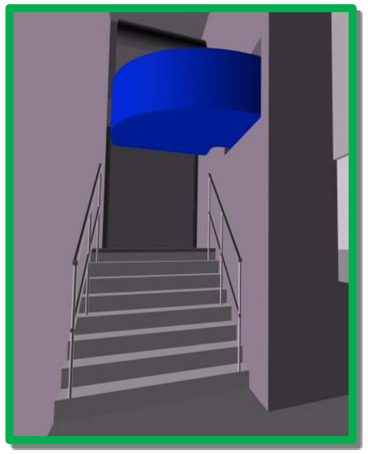
After the BIM models are set up, the model can be used to identify potential clashes at the earliest stages and resolve constructability issues before construction begins.



BIM model of the FPP shaft



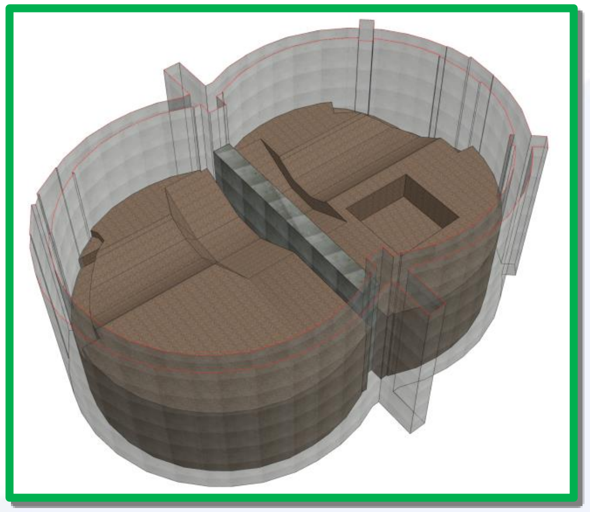
Walk tool - Navigate through a model as if you were walking through it



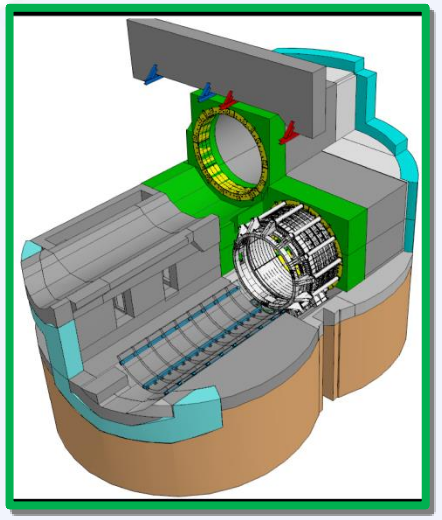
Identifying clashes

Use of BIM and 3D drafting on temporary work

Using the developed BIM model (mainly Civil and Structural model), together with 3D drafting technique provides more confidence to have a well-planned temporary work design. The interface details between temporary work and permanent work is checked in the 3D model, to avoid any misunderstanding due to the complexity of the congested structures inside the limited shaft area.



Final excavation profile of the shaft Considered both the profile of the temporary and permanent base slab

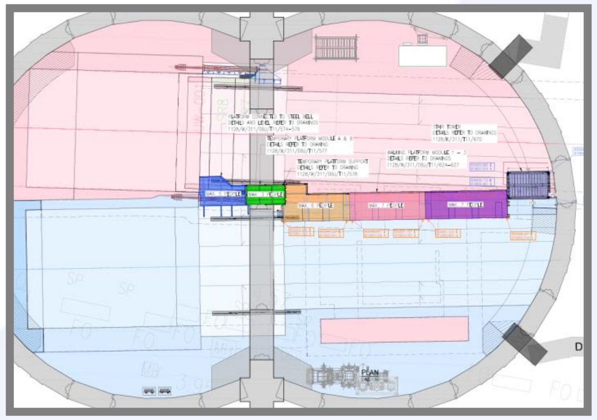


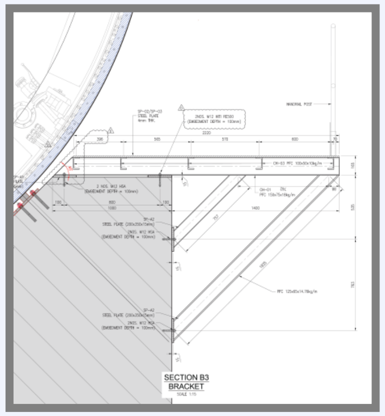
Overall 3D view of Concrete Bell, Steel Bell and Starwheel

Example (Design of Temporary access platform)

Traditional 2D Layout Plan & Section

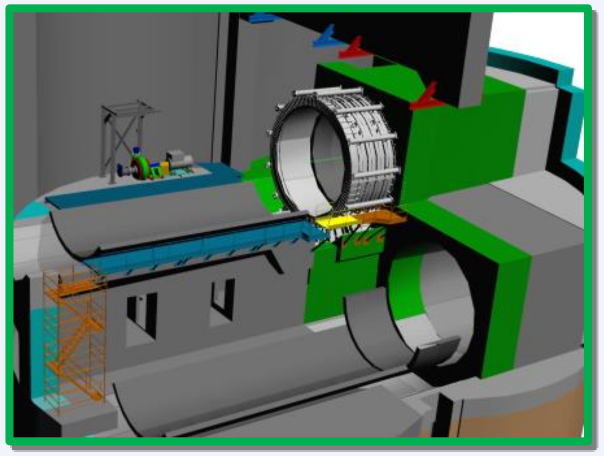
Hard to visualize access route due to complex forms of structures within shaft

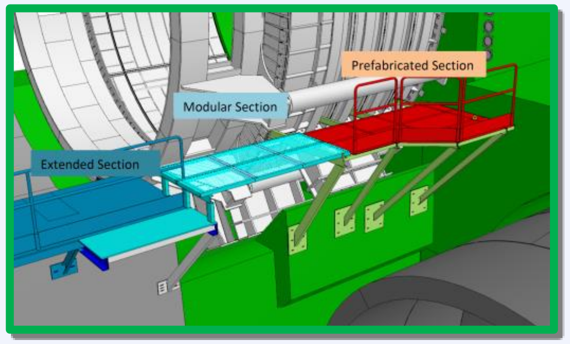




3D Layout together with BIM model

Fully visualize the access route and interface with surrounding structures





Delivery of innovative design package with Computerized Modeling

Background

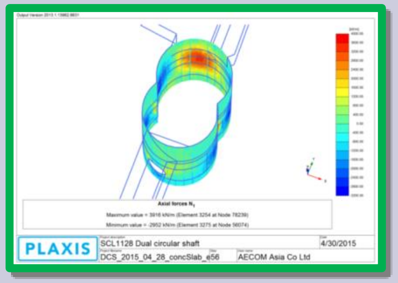
DBJV has successfully delivered the design package of the peanut shaft and the TBM launching structure, thanks to the good coordination between different designers, properly understanding the concerns and the proactive manner to tackle challenges.

Due to the complexity of the structures, advanced computerized modeling software have been utilized for our design. One of the best achievements is that DBJV has acquired the approval from the Buildings Department to adopt Plaxis 3-D as our major software to perform the ELS analysis of peanut shaft, which is the very first such practice in Hong Kong using 3-D Finite element software to carry out analysis and permanent design of a peanut shaped shaft with complicated behaviour.

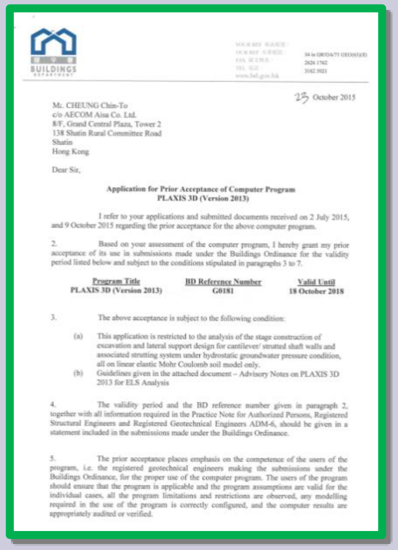
ARUP	Permanent structure design
AECOM	Peanut shaft ELS design
Bouygues TP	Concrete Bell stability Steel bell and Starwheel design
VSL	Pre-stressing system design

Role of different designers

PLAXIS 3-D	SAP2000 3-D	AUTODESK ROBOT
A finite element software intended for three-dimensional analysis of deformation and stability in geotechnical engineering	A finite element software intended for three-dimensional static and dynamic structural analysis	A finite element software intended for advanced structural simulation and analysis for large and complex structure
ELS design of the Peanut shaft To simulate the stress and movement of the shaft and the settlement induced to surrounding ground.	ELS design of the Peanut shaft. To better understand the structural behaviour and load path of the shaft	Concrete Bell stability checking and Steelwork design. Strong in output presentation for complicated structure.



PLAXIS 3-D Model
(Dual Circular Shaft at Area 1)


BUILDINGS DEPARTMENT

23 October 2015

Mr. CHEUNG Chin-To
c/o AECOM Aisa Co. Ltd.
8/F, Grand Central Plaza, Tower 2
138 Shatin Rural Committee Road
Shatin
Hong Kong

Dear Sir,

Application for Prior Acceptance of Computer Program
PLAXIS 3D (Version 2013)

I refer to your applications and submitted documents received on 2 July 2015, and 9 October 2015 regarding the prior acceptance for the above computer program.

2. Based on your assessment of the computer program, I hereby grant my prior acceptance of its use in submissions made under the Buildings Ordinance for the validity period listed below and subject to the conditions stipulated in paragraphs 3 to 7.

Program Title	BD Reference Number	Valid Until
PLAXIS 3D (Version 2013)	G0181	18 October 2018

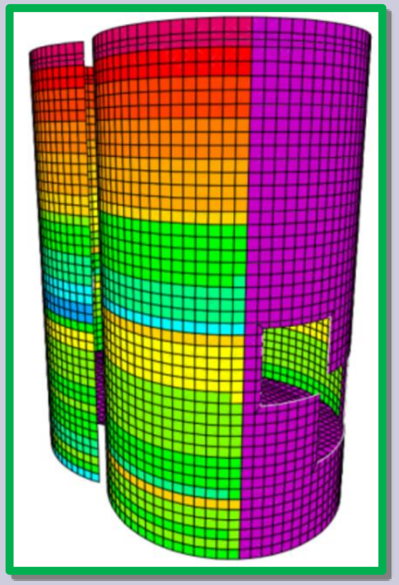
3. The above acceptance is subject to the following condition:

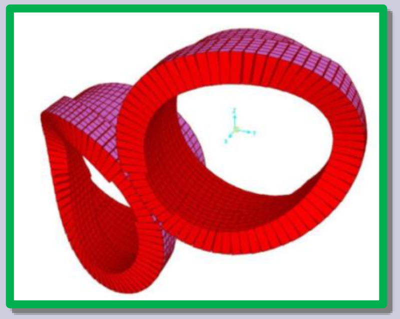
(a) This application is restricted to the analysis of the stage construction of excavation and lateral support design for cantilever/ strutted shaft walls and associated strutting system under hydrostatic groundwater pressure condition, all on linear elastic Mohr Coulomb soil model only.
(b) Guidelines given in the attached document – Advisory Notes on PLAXIS 3D 2013 for ELS Analysis

4. The validity period and the BD reference number given in paragraph 2, together with all information required in the Practice Note for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers ADM-6, should be given in a statement included in the submissions made under the Buildings Ordinance.

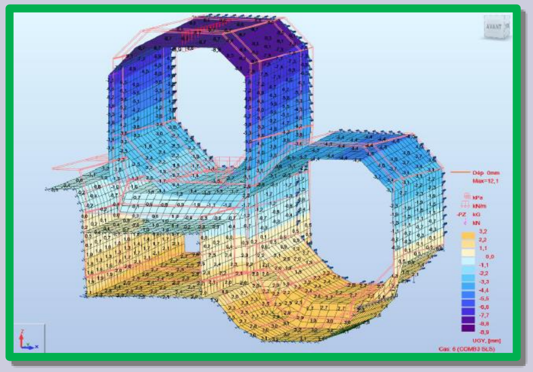
5. The prior acceptance places emphasis on the competence of the users of the program, i.e. the registered geotechnical engineers making the submissions under the Buildings Ordinance, for the proper use of the computer program. The users of the program should ensure that the program is applicable and the program assumptions are valid for the individual cases, all the program limitations and restrictions are observed, any modelling required in the use of the program is correctly configured, and the computer results are appropriately audited or verified.

Building Department Approval Letter
of using PLAXIS 3-D model

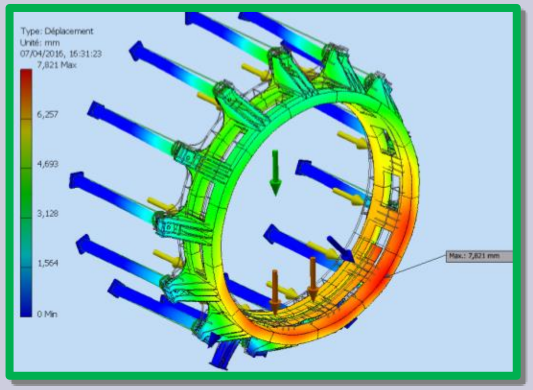




SAP2000 3-D Model
(Dual Circular Shaft)



AUTODESK Robot
Structural Analysis (Concrete bell)



AUTODESK Robot
Structural Analysis (Star Wheel)

Dragages - Bouygues Joint Venture

Conclusion

Complexity and challenges

The western tunnels of SCL1128 project required a ~40m deep launching shaft, with a very limited and congested site area surrounded by various existing tunnels and structures.

Comprehensive and meticulous planning and temporary work design scheme are therefore required to tackle all of theses challenges.

Excellent expertise in temporary works

The successful implementation of the Peanut Shaft and the TBM launching structure has demonstrated that the excellent expertise of the DBJV project team has enabled us to carry out an achievable innovative temporary work design scheme. **2,000 Tons saving in steel strutting** was achieved.

One of the remarkable credits is to have successfully acquired the approval from the Buildings Department to use PLAXIS 3-D modelling for our ELS design, which is the very first time in Hong Kong.

Great improvement in safety

By adopting innovative Peanut Shaft and TBM launching structure scheme, a significant improvement of site safety has been achieved, including a **Strut-free** shaft for TBM assembly, **60% reduction in ground settlement**, a **Safer workers' access**, a clear separation between TBM tunnelling work and permanent work inside the shaft, and a much larger working space for TBM launching, etc.

Deliver creative and innovative solutions

Both design schemes of the Peanut Shaft and Pre-stressed launching structure are **the First time implementation in Hong Kong**. The creativity of the DBJV project team enables us to deliver a tailor made innovative solution to tackle the challenges faced during the project.

Full contribution to safe completion of the project

In view of comparing the peanut shaft and the traditional rectangular shaft, the shaft excavation has been **completed ~5 months earlier**, thanks to the saving from the omission of waling/strutting and gaining in productivity in soft excavation. In addition, omission of heavy duty waling also allowed optimizing the P-way opening position to facilitate the NIL construction on the adjacent shaft.