RfR Tunnelling Questions for Independent Expert (Jan 2009)

1. *Based on your experience of world class projects could the design of the crossover tunnel be improved in any way?*

The proposed crossover tunnel beneath St Patrick's College playing fields is one of four crossovers along the route between the northbound and southbound tracks. In addition, there are 'turnbacks' at St Stephen's Green, Belinstown and north of the airport. The crossovers and turnbacks together allow LMVs to move between tracks to facilitate operational flexibility[EIS V1, Ch5, p66, and Ch6, p81-82]. The provision of turnbacks and crossovers are normal elements of metro systems, being required to give operational flexibility and efficiency. The justification given in the EIS for the locations of those proposed along this route appears to us to be logical.

The crossover tunnel beneath St Patrick's College is the only crossover that will be formed underground between Albert College Park and O'Connell Bridge (*i.e.* North of the Liffey), and it will be necessary to construct it separately from the running tunnels which it links together. This is because the TBMs that will be used for the running tunnels cannot be used for the construction of this structure, and therefore the crossover must be constructed as a separate operation from the boring of the running tunnels. Construction will either take place after the running tunnels have passed this location or in advance of the driving of the running tunnels in this area (see answer to Q3 below). The reference design anticipates that the crossover will be excavated using mechanical means and/or drill and blast technique. The methodology adopted by the contractor will be a function of the actual rock mass conditions encountered. The contractor will be able to make an assessment of the rock mass conditions during sinking of the ventilation shaft which is reasonably close to the crossover (and obviously at a similar depth within the rock).

The reference design shows the crossover tunnel to be located under the sports ground to the rear of the properties on the east side of Ferguson Road. This site has been selected for the crossover to avoid being directly beneath properties[EIS V1, Ch5, p65]. The crossover tunnel will be constructed in limestone bedrock. At this location, the running tunnels have more than 28 metres cover to the surface[EIS V2, Bk6, Ch5, p59] of which around 17m will be bedrock[Vol III, Appendix 2 to the Independent Experts' report]. The cover above the crossover will be less than this because the height of the tunnel is greater than the diameter of the running (bored) tunnels that it links together.

Insofar as the design of the permanent works is concerned, in the opinion of the tunnelling expert, there is little or nothing which can be achieved by way of improvement on the reference design. The location is considered appropriate both in terms of depth (a good thickness of bedrock cover above the excavation – see above) and is situated beneath open ground. The proximity of the emergency access and ventilation shaft allows the contractor to construct it before or after the running tunnels and so the Reference Design is not restrictive. The proposed structure is, in itself, simple, with no latitude for making it simpler or more efficient. It is anticipated that the contractor will use best practice in the development of his excavation/construction techniques; in other words, he will consider carefully how best to match the construction techniques and programme to the conditions encountered. In situations such as this, flexibility is required to match the construction process to the ground/groundwater conditions when the face is opened up.

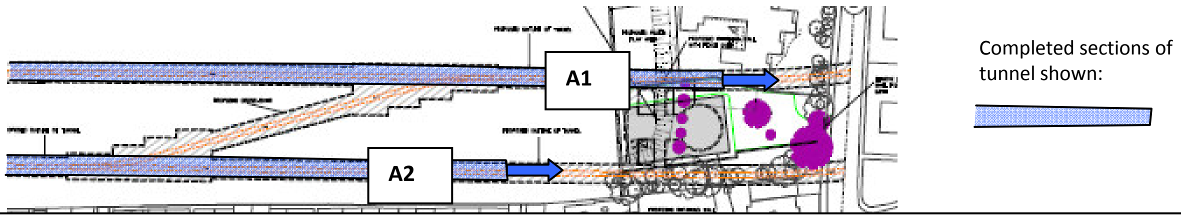
2. *There is a lack of construction methodology in the RO application in relation to the crossover tunnel. Is this normal/best practice?*

As stated in the response to Q1, the reference design indicates that the crossover will be constructed using mechanical excavation and/or drill and blast. In the opinion of the tunnelling expert, this is satisfactory at this stage of the design/consultation process in respect of the RO application; these are the only two methods available to the contractor. A detailed methodology cannot be developed (in respect particularly of groundwater control or of selection of appropriate roof support technology if needed) until knowledge of the tunnelling conditions is gained by actually opening up the ground. In the experience of the tunnelling expert, contractors undertaking this type of work have to submit detailed method statements for consideration and approval by the Owner's Engineer prior to commencing construction. Such method statements in these circumstances would reflect the contractor's assessment of the ground conditions and the proposed measures to construct the works in the most efficient manner. Significant detail and best practice will roll out at this point rather than in the RO application which, at best, can only anticipate the range of construction methodologies that could be applied; there is nothing in the reference design that could compromise best practice being applied to its construction or prevent the application of one available technology or another.

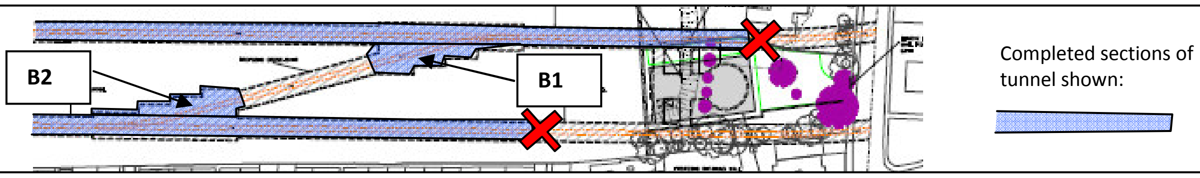
3. During the consultation phase the RPA stated that one of the four tender companies planned to construct the crossover tunnel in advance of the metro tunnels. We would appreciate your comments on this approach and the impacts it would have.

The Railway Order application (in the EIS) notes that the crossover tunnel may be excavated from St. Patrick's ventilation shaft[EIS, V1, Ch6, p95]. This (and the statement referred to in the question) reflects a genuine choice that contractors have in relation to this structure; either it will be formed after the running tunnels have progressed past the junctions with the crossover tunnel or it will be formed before the running tunnels reach this location. There is a range of matters to take into account before making this choice, principally reducing to a minimum the disruption that one operation will have on the other. The following sketches and table illustrate the issues that influence this decision:

i. Crossover formed from running tunnels



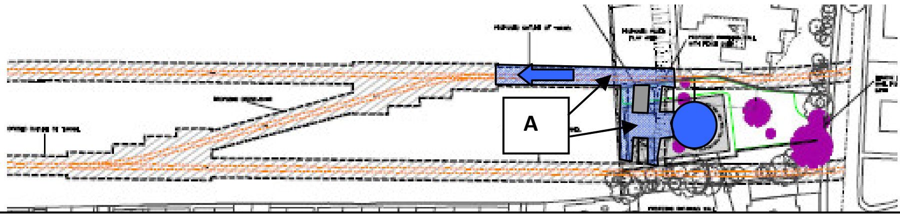
Both running tunnels (A1 and A2 above) advanced by TBM beyond the junction with the crossover tunnel. Behind each TBM is the transport and support infrastructure for the TBM (conveyor or railway for spoil out and materials in, electricity, hydraulics *etc*)



Running tunnel linings need to be removed and then the tunnel at the junctions (B1 and B2) will be widened out. Whilst this is done, the TBM operation will be interrupted because it will not be possible to maintain the transport and support infrastructure past the junction works. The construction of each junction would disrupt the progress of the TBM in that tunnel whilst the work is completed (either the TBM would stop in the affected running tunnel for the duration of the works on the junction or there would be frequent interruptions to its progress). Spoil from the junction caverns would be removed *via* completed sections of running tunnels.

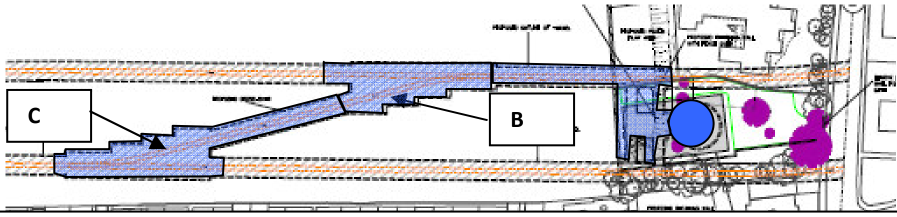
Once each junction cavern is complete, the TBM infrastructure can be re-established and boring of the running tunnels can resume without further interruption. The crossover itself (C) can be completed between the junction caverns whilst the TBM is operating (from one end or the other or in both directions alternately or simultaneously).

ii. Crossover formed from emergency access and ventilation shaft in advance of bored running tunnels



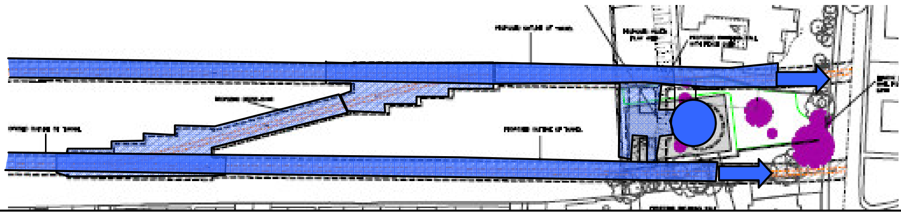
Completed sections of tunnel/shaft shown:

Shaft created and the section of the East running tunnel between the shaft and the junction cavern formed by excavation or drill and blast (A). Spoil removed *via* the shaft.



Completed sections of tunnel shown:

Junction cavern formed from East running tunnel (B), followed by crossover and West tunnel junction cavern (C).



Completed sections of tunnel shown:

Running tunnels can now be advanced past this location (TBM pushed through sections of tunnel already formed) without interruption.

Form crossover after running tunnels		**Form crossover from shaft in advance of bored running tunnels**	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
• Less spoil removed *via* ventilation shaft. • Minimises construction and spoil removal activities at the surface around the shaft. • Allows running tunnels to be completed without interruption.	• Disruption to TBM progress due to interface at the junction cavern. • Safety issues underground arising from the need to manage two operations at once and the interfaces between them in a congested underground environment (there is no increased risk of tunnel collapse).	• No disruption to TBM progress. • Faster completion as introduction of materials for the crossover will not be interrupted by servicing TBM. • More flexibility programming the works. • Gain experience of conditions and groundwater control without impeding TBM progress if forward investigation/ground treatment slows construction down	• More spoil will come out of the shaft and have to be hauled away than would come from the shaft construction alone. • Increased time for construction and spoil removal activities at the surface around the shaft.

In addition to the crossover tunnel described above (and the turnback facilities), there will be cross passages at regular intervals along the tunnel to allow passengers to pass from one tunnel to the other in an emergency; these will all be formed (by excavation or drill and blast) after the bored tunnels are complete[EIS, V1, Ch6, p89].

4. *Does using three TBMs significantly increase the cost of the project?*

The number of TBMs that will be deployed on the bored tunnel south of Albert College Park is two; one for each running tunnel[EIS, V1, Ch6, p92]. The bored tunnels in the airport section, will be driven using a single TBM, driving from the south in each tunnel in turn[EIS, V1, Ch6, p92]. The TBM for the airport tunnels will either be a third unit or one of the TBMs used in sections 106 and 107 used for this task before or after the city running tunnels are complete.

It is difficult to say how the number of TBMs (three instead of two) would affect the overall cost of the project. The costs that are relevant here are capital costs of purchasing (or refurbishing) the TBMs, shipping them and constructing them on site. Operating costs per metre run of bored tunnel should not be affected by the number of units deployed, although there could be knock-on efficiency savings from being able to progress tunnels at the airport concurrently with those in the city.

The TBMs themselves will cost in the order of €7 million to €8 million each to purchase, ship and assemble on site. The tendering contractors are likely to have differing approaches to the costing of the TBMs on the project

- It may be the contractor’s policy to amortise the cost over several projects including Metro North and other projects which they would hope to win in the future. If they do this, they would allocate only a proportion of the capital cost of the TBM to the project.

- The contractor may put the full cost of the TBMs against this project.

- The contractor may already have some or all of the TBMs required in its plant holding, so the capital cost against the project would be relatively low (reflecting primarily refurbishment, shipping and assembly).

- The contractor may enter into a leasing arrangement with the TBM manufacturer or possibly a sale and buyback.

All of the foregoing make it impossible to estimate how the number of TBMs employed would influence the cost of the project in terms of the capital cost of the TBMs themselves and how that cost would be allocated.

Generally speaking, the more TBMs on site, the shorter the overall construction period. This does influence cost by reducing time on site, and hence overhead which includes the contractor’s preliminaries for office accommodation, engineers, project managers, transport, hired plant etc. The way in which the different contractors carve up these costs is a function of their approach to putting together the most competitive bid.

5. *Do you have any experience of post operational adjustments to metro lines? Would it be possible to add stations/stops along the route?*

Post operational adjustments to the metro lines by way of adding additional stations/stops are, in the experience of the tunnelling expert, extremely rare; most would consider them unheard of. Any such activity, especially on the tunnelled section of the system must lead to cessation of operations whilst the new works are constructed.

6. *Would it be possible to convert the Ventilation shaft to a station at some stage in the future?*

No, see answer to Q5.

7. *Is the design of the ventilation shaft in relation to the positioning of the 2 tunnels significant?*

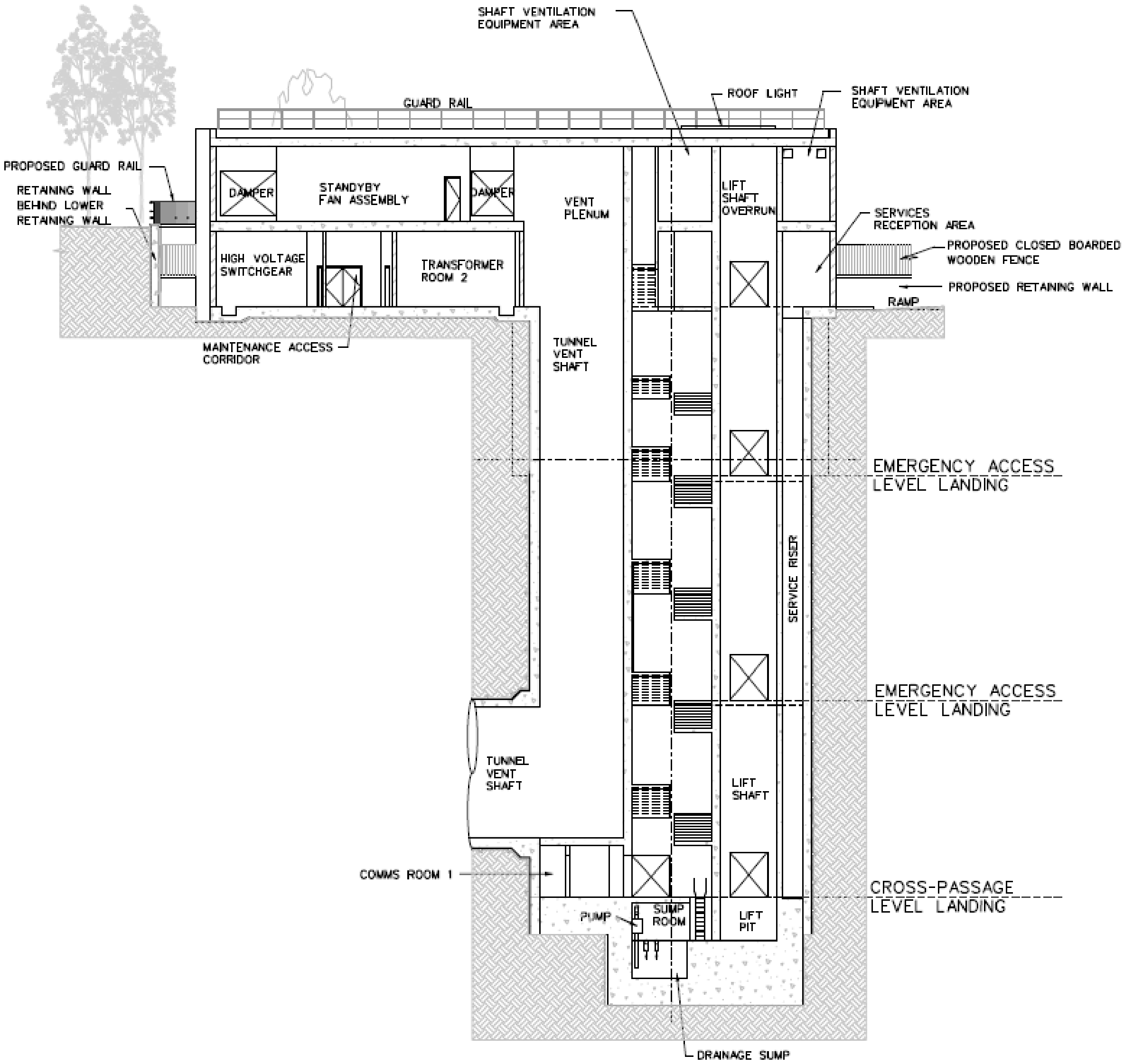
The alignment runs from Griffith Avenue to Drumcondra in bored tunnels. As the length of the bored section of tunnel between Griffith Avenue and Drumcondra stations exceeds 1km, an emergency access and ventilation shaft is required for fire safety and for operational reasons, approximately at the midpoint of the section[EIS, V1, Ch5, p63 & Ch6, p78]. The positioning of this shaft in relation to the surface and the running tunnels is the most expeditious; it is approximately midway between the two stations and is between the two running tunnels. Its location in relation to the tunnels ensures that the underground route for emergency egress from either tunnel is as short as possible. Similarly, its proximity to the tunnels (by being between them) reduces to a minimum the length of additional tunnels that will be required for the purposes of ventilation. Its surface location is in the corner of a sports pitch. Whilst the site access is onto rather narrow residential streets, emergency vehicles and personnel would be able to gain access to it *via* St Patrick's College. This surface location would ensure that those evacuated from the tunnels in an emergency would emerge into an open space and not spill onto the streets.

A shaft offset from the tunnel line (*e.g.* to facilitate access for emergency vehicles from larger roads or to move the shaft building and ventilation fans further away from buildings) would require the construction of additional ventilation/draught relief tunnels, thereby increasing the cost of the project. It is probable that operational costs would also be higher due to a requirement for higher power ratings for ventilation fans (and there may be implications for meeting thresholds in relation to airborne noise levels).

8. *Is it likely to increase the noise in this area? (Rupert Taylor has stated that he did not do a noise assessment in relation to the ventilation shaft.)*

In addition to the impacts of airborne noise from periodic testing of emergency ventilation fans in the building at the top of the shaft (which is considered in the EIS and has been covered in the independent experts' report), the possibility of airborne noise being transmitted from the tunnels to the surface *via* the shaft has been raised as a concern by some residents. The shaft, when complete, will contain staircases, lifts, floors and doors and there will be a building over the top of it. An excerpt from the relevant Railway Order drawing is reproduced below to illustrate this[Railway Order drawing MN-VT 106 C-D2] [1].

[1] http://www.dublinmetronorth.ie/Downloads/PlanofProposedWorks/05-StructuresDCCBook%201of2/34-LMN000VB106002A.pdf



SECTION A-A

SCALE 1:200

The barrier effects of the infrastructure within and above the shaft itself (and within the tunnels linking it to the running tunnels) will be such that, in the opinion of the independent noise expert, there is no possibility of airborne noise generated by LMVs in the running tunnels being transmitted to the surface *via* the stairwells and lift shafts providing they are designed so as to avoid resonance being set up in the structural elements as a result of air pressure waves in front of trains. The tunnel vent shaft is a potential conduit for the transmission of airborne noise, but this will be fitted with attenuators (and enclosed within the building at the surface) which should provide adequate mitigation.

Therefore, providing the shaft designers recognise the need to avoid resonance of the structure due to air pressure waves, the following statement in the EIS is considered by the independent noise expert to be reasonable both for the generality of the bored running tunnels in this area and for the shaft location in particular:

4.4.2.2 Operation
LMV Noise
The alignment is in bored tunnel in this area. No airborne noise impacts will occur. No noise mitigation measures are required to mitigate airborne noise from the LMVs in Area MN106.[EIS, V2, Bk6, Ch4, p42].

There is potential for groundborne noise to be propagated *via* the shaft lining in a different manner to solid ground (the surface waves that can develop in these circumstances are usually of greater magnitude than body waves[2]). However, this is not inevitable providing the designers incorporate appropriate mitigation in the detailed design (probably damping at the surface). We note that, in this location, the trains will be running on 'floating tracks' and so the level of groundborne noise is likely in any event to be low within the ventilation shaft building and to be undetectable at locations outside the limits of the shafts and tunnels.

9. Does the depth of the tunnels approaching the Griffith Ave station conform to best practice?

Best practice for underground tunnels, is achieved through design which can cope with a number of interrelated factors that affect tunnel depths. The principal factors to be considered in design are:

- The range of depths that is possible at this location, taking account of the relationship between this station, Drumcondra Station, and the tunnel portal and constraints imposed by maximum safe gradients and curvature for the metro.
- The ground conditions with respect to tunnelling and minimising ground movement.
- The ease and speed with which passengers can gain access to the platforms and leave the station.

Review of the reference design shows the tunnels entering and leaving the Griffith Avenue Stop to have between 3 and 5 metres of rock cover overlain by +12 metres of glacial till, more than 15 metres in total to ground level from the top of the tunnels[Independent Experts' Report, Vol III, Appendix 2 and drawings referred to in that appendix].

It appears that a balance has been struck at this station between ensuring that the depth of the station meets architectural/human requirements, whilst ensuring bedrock cover to the tunnels to minimise the risk of ground movements. At the depth indicated, movement of passengers will be relatively easy. Compare this with, say, London Underground where some station platforms are up to 40 metres deep but still transfer millions of passengers each year.

10. In your experience is a 30m zone of influence appropriate given the varying depths along the route

A 30m zone on either side of the tunnels has been used as the basis for identifying the houses (and other non-commercial properties) that will be covered by the RPA's Property Owners' Protection Scheme[recent brochures and EIS, V2, Ch9, Books 2, 5, 6 and 7]. It is not a zone within which settlement is <u>expected</u> to occur but a zone within which settlement could occur under unfavourable circumstances.

It is common practice to define a 'zone of influence' for settlement effects at a distance equal to the depth of the excavation (or, in the case of bored tunnels with rock cover, at a distance equal to the depth of the superficial materials). The RPA has indicated that the 30m they have chosen

2 A body wave is a wave within a material (such as a wave initiated by vibration underground and transmitted to the surface where it is experienced as ground borne noise) whereas a surface wave is a wave at an open surface or the interface between two different materials of different acoustic properties.

is not absolute; where the worst case settlement predictions indicate that the zone of influence could extend outside the 30m zone, they taken the predicted 2mm settlement contour as the limit of the zone[EIS, V2, Bks 2, 5, 6 and 7, Ch9, Table 9.1 and information provided by RPA to the independent experts].

In our opinion, given that the depth to the bored tunnels is only rarely greater than 30m, and the maximum thickness of superficial materials is generally less than 30m[Independent Experts' report, Vol III, Appendix 2], the zone defined for the purpose of the Property Owners' Protection Scheme is appropriate to the anticipated ground conditions (providing it extends beyond this zone where the predicted 2mm settlement contour lies more than 30m from the tunnels, which we believe it does). We agree with the authors of the relevant sections of the EIS that damage to buildings is extremely unlikely to occur where settlement is less than 2mm.

11. *In your experience is a 50m zone of influence appropriate in relation to the underground stations and should this also apply to the ventilation shaft.*

See answer to Q10; 50m is more than adequate as a 'zone of influence' for underground stations. The ventilation shaft will have a total depth of approximately 35m but the superficial materials are less than 15m thick. Further, shafts by their vertical form and cylindrical shape tend to have a smaller zone of influence than linear excavations or tunnels. Accordingly, we do not consider that it would be necessary for a 50m zone of influence to apply to this structure.

12. *Are the limits of deviation along the entire route in accordance with best practice?*

In the experience of the independent tunnelling expert, projects such as this always specify limits of deviation to define the corridor within which the contractor can design the works, but once the line of a tunnel has been chosen; the limits of deviation are not a margin for error in implementing the works. Designs and design changes are, in the experience of the tunnelling expert on similar projects, likely to be subject to detailed method statements and likely to need approval from the employer before construction can commence. On this basis, the limits of deviation do accord with best practice.

13. *Does the zone of influence normally automatically adjust should any lateral deviations occur in these types of projects?*

We have checked with the RPA and can confirm that the limits of the zones within which the Property Owners' Protection Scheme will apply have been measured from the outer limits of the works (*i.e.* assuming that the tunnels and stations are constructed at the outer limits of deviation). There is therefore no need for these to be adjusted if the contractor were to vary his design alignments towards the limits of deviation.

14. *Could you explain how a TBM is pulled through a station box and whether or not this is a noisy procedure.*

The TBMs are more likely to be pushed through the station boxes rather than pulled. The TBMs in normal operation are moved forward by hydraulic rams thrusting the shield and its cutting head onto the tunnel face whilst at the same time the rotating cutterhead is excavating and removing spoil from the face. The hydraulic rams, which provide the forward thrust push against the segmental tunnel lining last erected in the protective tailskin of the shield.

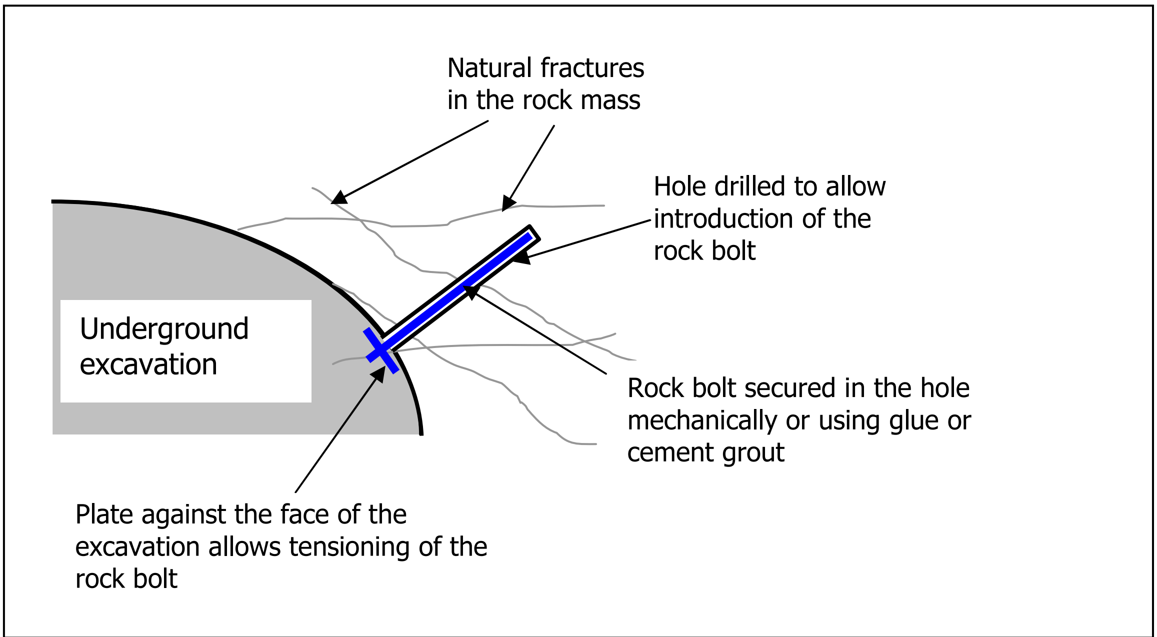
Thus when the TBMs enter a station box they will be propelled forward through the box by thrusting against invert segments (the lowest segment of the segmental tunnel lining) only. It would be unusual to have to convert this efficient system into one that pulls. It can be confidently anticipated that this operation will be almost noiseless. The thrust rams are powered by electro-hydraulic power packs which are very low noise emitters. Of the activities that will take place within station boxes whilst they are fully or partially open to the atmosphere, this activity will not contribute to the overall construction noise.

15. We would appreciate your comments in relation to any precautions that need to be put in place in the event of a major flood (e.g. 50 year or 100 year as expected in Paris within the next decade)

It should be noted that 50 year or 100 year events can occur anywhere (not just Paris) at any time and that the interval between them can be quite short. Design of metro schemes must take many factors into account including flood hazard. The designers of the system will anticipate ways in which flood water occurring at the surface could get into the tunnels and stations and put in place measures in the detailed design to ensure that this cannot occur. Assuming that good design practice is adopted (and there is no reason to suppose that it won't be), there should be no risk to the system from 50 or 100 year event storms. The independent tunnelling expert is not aware of any tunnelled metro systems being significantly affected by flood events, and that includes the London Underground.

16. Is the use of rock bolts best international practice or are there other options?

Rock bolts are used to provide either support or strengthening or both, and are used in underground openings to prevent them collapsing or deforming and giving rise to ground movements at the ground surface. In the bored sections of tunnel, ground support will be provided by the lining rings that are installed in the tunnel as an integral part of the TBM construction technique. Installation of rock bolts is one of a number of methods which can be used for ground support/ground anchorages in underground excavations. They can be used before an integral lining is placed, being covered by it, or where the installation of structural linings is not an integral part of the final design (*e.g.* the crossover tunnel, the cross passages and station excavations in rock). Rock bolts work by 'knitting' the rock mass together sufficiently before it can move enough to loosen and fail by unravelling piece by piece (see sketch below) so that the rock mass can provide for itself a natural arch that creates stability around the excavation and thus prevent movement of the larger mass of ground above.



There are many different types of rock bolt and different methods for fixing them; the choice of bolt in a given situation depends upon a detailed assessment of the ground conditions and the nature of support needed. The key features of their installation is that a hole must be drilled to accommodate the bolt (sometimes this is drilled using the bolt itself – a self-drilling bolt), the bolt must be secured in the hole (by using glue or cement grout or by use of expanding sections of the bolt to 'wedge' it into the hole), and it must be secured against the face of the excavation and (often, but not always) tensioned. The drilling involved to install a rock bolt is similar to that required for drilling a blast hole, and therefore the impact of this activity will be no greater than that associated with drilling and blasting.

The use of rock bolts does conform with international best practice when they are the appropriate method for providing strength and support. This is a method that is regulated by a range of international and national codes (*e.g.* in the UK it is covered by BS 8081:1989 *Code of Practice for Ground Anchorages*, partially superseded by BSEN 1537:2000, *Execution of Special Geotechnical Work-Ground Anchors*). Both of these documents lay stringent requirements on users in terms of application, materials, installation, testing and monitoring. Their use is universal and, properly installed they are effective and economic in providing adequate ground support.

There are other options for ground support. Where support to excavated rock surfaces is required, and rock bolts are unsuitable, internal strutting in the form of steel arches and lagging bars can be used. This has the disadvantage of being slower and more expensive than the installation of rock bolts and requires a larger overall excavation profile to accommodate the specified permanent works dimensions.

17. Will the construction of any of the crossover passages require the use of rock bolts?

It is very likely that rock bolts will be used in conjunction with sprayed concrete in the crossover tunnel and the cross passages (where constructed in rock) to provide rock support and primary structural lining. Whether or not secondary lining will be required will depend on the rock mass characteristics and the nature of loading on the rock bolts and sprayed concrete (which are both structural elements of the support system). This system is well understood by tunnel designers and there is much relevant precedent experience for its use. It has the advantage over other methods of being flexible and relatively quick to construct compared to excavations that then have to be supported by pre cast segmental concrete or cast iron tunnel linings, or cast in-situ concrete linings.

18. What type of emissions are caused by a tunnelling project of this nature?

In addition to groundborne noise and vibration, there are only two emissions that arise from the tunnel construction itself:

- ***Groundwater from open face excavation such as crossover tunnel, cross passages and station boxes/shafts.*** Heavy groundwater ingress to workings is usually considered to be detrimental to the excavation/support process and is particularly to be avoided where it could cause drawdown of the water table. In this project, it is likely that groundwater ingress will controlled by fissure grouting in rock or consolidation grouting in soils to reduce the ingress to acceptable levels. In a well managed underground excavation site, there should be no possibility of groundwater being chemically contaminated but it is likely to pick up particulate matter (silts, sands *etc*). Groundwater which enters the workings will be pumped to the surface where it will be treated to remove particulate matter before discharge into the local drainage systems. Silts, sands *etc* arising from the treatment process will be deposited in spoil storage and disposal facilities with other tunnel arisings.

- ***Where blasting occurs, the principal gaseous products are carbon dioxide (CO_2), nitrogen (N_2) and steam (H_2O), with small amounts of carbon monoxide (CO) and nitrogen oxides (NOX).*** CO and NOX will be generated at the blast site and released locally into the atmosphere underground. CO and NOX are poisonous and their presence is dealt with by dissipation using the tunnel ventilation system. No workers may enter the blast zone or other areas of the tunnel until a safe threshold limit value (TLV) for NOX and CO has been reached. Monitoring of the atmosphere is continuous after a blast, at the face, along the tunnel length and at tunnel portals/shaft tops to ensure that designated TLVs are reached before re-entry is allowed to the workplace. By the time the air has exited the tunnel workings *via* the passive ventilation system it will be sufficiently diluted for workers or anyone passing the worksite to be unaware of its presence and the atmosphere will be safe. Concentrations of CO and NOX reduce very rapidly away from the blast site and monitoring would normally only detect concentrations above TLVs within the tunnels themselves.

Explosives contain their own oxidising agents, so the explosive reaction occurs without consuming the oxygen in the surrounding atmosphere. However, in underground operations, the production of CO_2, N_2 and H_2O is sufficient to dilute the oxygen content below viable levels close to the blast. This is dealt with by the tunnel ventilation system.

Other emissions from the operation of the metro have caused public concern (*e.g.* electromagnetic effects, PM10s in ventilation exhausts). These have been covered in the chapters of the EIS dealing with Human Health but are beyond the remit and expertise of the Independent Engineering Experts.

Prepared by the Independent Engineering Expert panel for Dublin Metro North
February 2009 (minor revisions March 31st 2009)