METRO NORTH

ORAL HEARING

PROOF OF EVIDENCE

CONSTRUCTION METHODOLOGY

Richard Tucker

Tuesday 7th April 2009

Railway Procurement Agency

Metro North Oral Hearing
Proof of Evidence
Underground Construction Overview
Richard Paul Tucker

1.0 INTRODUCTION

SLIDE 1

My name is Richard Tucker. I am a mining Engineer with over 20 years experience in the design, planning and construction of major underground and civil engineering projects in Ireland and Europe, including the Channel Tunnel, Jubilee Line Extension Project and Cross rail (UK), the Alp Transit Tunnels and Central European Nuclear Research Particle Physics Tunnels (CERN Switzerland), the Lisheen Mine Development (Co Tipperary) and the Dublin Port Tunnel.

I have a Bachelor of Engineering degree with Honours form the Camborne School of Mines and I am a member of the British Tunnelling Society. I am an Associate of London Bridge Associates a specialist Underground consultant and contractor.

2.0 SCOPE OF EVIDENCE

The scope of this Evidence is to give an understanding and overview of the Civil Engineering and Mining methods that may be employed to construct the underground sections of Metro North.

My Evidence is structured as follows:

SLIDE 2

For Metro North the principle underground elements of the work to be constructed are:

- Mined Tunnels
- Cut and Cover Tunnels
- Stop Boxes or underground stations and Shafts
- Bored Tunnels

I will give a description of the possible individual excavation and support techniques that could be appropriate for the construction of the underground elements of Metro North. I will then link these techniques together to describe the construction of Mined Tunnels, Cut and Cover Tunnels and Stop Boxes.

I will then describe the use of Tunnel Boring Machines that could be used for the construction of the bored tunnel separately combining excavation and support methods.

SLIDE 3

Mined Tunnels will be constructed at St Stephens Green to form the turn around loop tunnels, for the crossover caverns situated just north of St Stephens Green and St Patricks College and for cross passage excavation between the running tunnels.

SLIDE 4

Cut and cover Tunnels will be constructed from Northwood to Albert college Park, and in areas along the Swords Road beneath the Malahide Roundabout and across the R132 at Fosterstown.

SLIDE 5

Stop Boxes will be constructed to form the Stations at the Airport, Ballymun, Dublin City University, Griffith Avenue, Drumcondra, Mater Hospital, Parnell, O'Connell Bridge and St Stephens Green, there is also an intervention shaft to be constructed at St Patricks College.

SLIDE 6

Bored tunnels will be constructed beneath the Airport and from Albert College Park to St Stephens Green, will be constructed using tunnel boring machines tailored to the specific ground that they will encounter.

SLIDE 7

The principle excavation for **Mined Tunnels, Cut and Cover Tunnels and the Stop boxes** will be carried out with hydraulic excavators coupled with the following techniques to break the rock to allow it to be excavated.

- Chemical Splitting
- Impact Hammer
- Drill and Blast

SLIDE 8

To provide support to the excavation the following methods or combination of methods could be used.

- Sprayed Concrete Support
- Rock Bolt Anchoring
- Soil Nailing
- Rigid Retaining Walls

Firstly I will describe the techniques that aid excavation that could be used on Metro North

2.1 Excavation

SLIDE 9

Many factors are considered when deciding on particular methods of excavation within a project.

These include amongst others, the ease at which ground can be excavated, the volume of ground to be excavated, operational constraints such as safety and environmental considerations, as well as the type of excavation equipment available and contractual constraints.

These factors are assessed by the Contractor to determine the most effective means of excavation.

The ease of excavation is in part determined by the geology of the ground to be excavated. In the case of excavation of rock, this is controlled by the strengths of the intact rock and the frequency, orientation and condition of natural fractures within the rock mass.

For tunnels and underground structures, further consideration is made with respect to

- the ability of the surrounding ground to remain self-supporting and
- the local hydrological conditions.

To enable the rock to be excavated and removed from the work face it first has to be broken up or fractured to allow it to be dug. Excavation of fractured rock can then be carried out using hydraulic excavators.

Typical techniques proposed to fracture the rock include:

- Mechanical or Chemical Splitting the rock
- Mechanically Breaking the rock
- Drilling and Blasting the rock

2.2 Splitting

SLIDE 10

Rock Splitting facilitates excavation by inducing fractures into the rock mass. There are two broad categories of splitting, mechanical splitting and chemical splitting. Splitting provides an effective means of breaking mass concrete and rock without risk of fly rock, noise, ground vibration toxic gas or dust.

Both follow the same principle of the application of stress in a drill hole to cause fracture of the rock due to tensile failure. The fractured rock is then able to be excavated by hydraulic excavator or similar plant.

For **mechanical splitting** most of the equipment used is hand-held and as a consequence, splitting of large volumes of rock is not practical. It has thus not been considered as appropriate for Metro North.

Chemical splitting generates a stress in the borehole by the expansion of a chemical agent. These agents usually comprise of a dry inorganic silicate compound, which when mixed with water and placed in the drill hole, expands inducing stress into the rock, causing it to fracture. The time taken to generate sufficient stress can be as short as 6 to 9 hours.

In general, rock splitting requires further disintegration of the rock using mechanical breakers to allow excavation. The cost in both time and materials for rock splitting using chemical expanding agents is higher than the same using blasting. However, splitting using chemical expanding agents is effective for areas where traditional blasting can not be carried out.

Chemical Splitting and Impact breaking could be used for excavation through rock at Stop Box locations i.e. O’Connell Bridge, St Stephens Green etc.

2.3 Mechanical Breaking

SLIDE 11

Mechanical breaking induces new fractures and exploits existing discontinuities in a rock mass by subjecting the rock to repeated and localised percussive blows. When the rock has been adequately fractured and loosened, excavation by hydraulic excavator or similar plant can proceed.

The standard method of applying the impact blows is by the use of a hydraulic breaker fitted to the articulated arm of an excavator. The breaker performs like a hammer and chisel by driving a hydraulic piston against an integral metal chisel. The resultant energy is then transferred into the rock. Particularly strong and massive rock may require prior fragmentation using alternative methods such as chemical splitting before the use of mechanical breaking to achieve efficient excavation.

Specialist plant has been developed to carry out mechanical breaking in tunnels.

This method of excavation could be suitable for the development of cross passages and the St Stephen’s Green loop tunnel.

2.4 Drill and Blast

SLIDE 12

The basic principle of Drill & Blast as a method of tunnelling is to fracture an in-situ rock mass by detonating high explosive which produces a high pressure gas. The broken rock can then be easily excavated and removed from the tunnel face using hydraulic excavators and loaders.

The sequence of working is relatively simple and follows well defined steps.

The blasting pattern is designed and laid-out on the tunnel face by the blasting engineer. Various types of blasting patterns are used depending on the nature of the rock mass to be blasted and the required profile of the tunnel.

By following the blasting pattern, holes are drilled into the rock to the required depth. Dedicated plant known as drilling jumbos or boomers are used to drill the holes at diameters of typically 40 to 80mm.

The holes are then charged with explosives and primed with detonators. The amount of explosive used depends on several factors including the depth of excavation required per blast, known as the "pull", the in-situ strength of the rock, the structural pattern of the rock mass and environmental constraints at the surface.

When the explosive contained in the borehole is detonated, high pressure gases are formed expanding in the drill holes and fracturing and shattering the rock.

The broken rock can then be excavated and removed from the tunnel or work place using by mechanical excavators and dump trucks.

2.5 Bulk Excavation

SLIDE 13

Bulk excavation is carried out in ground that is soft or has been fractured enough to so that it can be easily dug.

The types of plant suitable for this excavation method are standard, hydraulic excavators and loaders. Excavators initially load the excavated spoil for removal, directly onto wagons.

In the case of excavation from surface to depth, as the excavation proceeds downwards, the spoil is typically loaded into skips which are then hoisted to the surface by crane and transferred to wagons for off-site disposal or re-use.

On Metro North, the areas of work where this method of excavation is likely to be used is Parnell Square stop and the early excavation stages of excavation for all the stop boxes.

2.6 Support

SLIDE 14

Support measures, either as permanent or temporary support, are required to ensure excavations remain open and safe and their choice is dependant primarily on the local geological conditions, space constraints and environmental considerations such as settlement and dewatering.

Depending on the nature of the excavation process, support measures may be installed prior to, during or immediately after the excavation has taken place.

Typical main support methods applicable to Metro North include:

- Sprayed Concrete Support
- Rock Bolt Anchoring

- Soil Nailing
- Rigid Retaining Walls

Support falls into two main categories, temporary and permanent.

Temporary support provides a safe environment for tunnelling and bulk excavation to progress but is not sufficient to satisfy the permanent support design.

Permanent support satisfies the loading requirements of the design and can be placed once the excavation is complete or prior to excavation.

2.6.1 Sprayed Concrete Support and linings (SCL)

SLIDE 15

Sprayed concrete is commonly used as a temporary support measure although it is becoming more accepted and utilised as a permanent solution for tunnel support and linings. It is often referred to as "shotcrete" and is essentially quick setting concrete sprayed onto an excavated surface. This is achieved by the concrete containing small aggregates to allow for spraying and additives to promote fast curing times and therefore high short-term strength required for early support.

The tensile strength is often augmented by the addition of polypropylene or steel fibres to the concrete mix.

Shotcrete is particularly suitable for tunnels and excavations of non-circular profile, complex geometries at tunnel intersections and open-cut slopes. Shotcrete alone is not viable as a support measure and is strengthened with reinforcement mesh and fibres and used in conjunction with other methods including arched girders and rock bolts.

On Metro North, shotcrete support could be used to provide temporary support to excavated slopes and mined tunnels including cross-passages, the crossover caverns to the north of Drumcondra and at St Stephens Green, the loop tunnel and stop boxes excavations in rock.

2.6.2 Rock Bolting (bolts, anchors and dowels)

SLIDE 16

Rock bolting is a well established method of providing support to all types of excavations in rock including high-angled slopes, vertical faces and around tunnel profiles. Bolts may be installed gradually as excavation progresses to provide immediate support to the "open ground" or conversely and particularly in the case of tunnels, can be introduced into the ground ahead of the tunnel face or at junction locations to ensure stable ground conditions during tunnel advance. In simple terms, the purpose of rock bolts is to "knit" together the rock mass by forming zones of compression between bolts to provide stability and this is achieved by bolting to a predetermined pattern based on the prevailing geological structure of the rock mass. Isolated and individual bolts may be used to inhibit movement of specific blocks of rock through wedge failure for example.

Rock bolts generally consist of plain steel rods with a mechanical anchor at one end and a face plate and nut at the other. They are always tensioned after installation. For short term and temporary applications the bolts are generally left un-grouted. For more permanent applications or in rock in which corrosive groundwater is present, the space between the bolt and the rock can be filled with cement or resin grout. Dowels or anchor bars generally consist of deformed steel bars which are grouted into the rock. Tensioning is not possible and the load in the dowels is generated by movements in the rock mass. In order to be effective, dowels have to be installed before significant movement in the rock mass has taken place.

Installation of the bolts is undertaken using plant similar to or the same as that described for drill & blast excavation. In this case, the drill hole is filled with the rod and not explosives.

It is envisaged that rock bolts and anchors may be used in the loop tunnel, the tunnel cross passages and crossover excavations and the stop box excavations in rock.

2.6.3 Soil Nailing

SLIDE 17

Soil nailing is essentially the same as rock bolting but used primarily in open-cut soil slopes. The nails are however, almost always fully bonded along their whole length with cement or resin grout and are not pre-tensioned. Their main purpose is to stop cantilever and block failure from the face of the slope and to inhibit shear failure within the soil mass.

2.6.4 Rigid Retaining Walls

SLIDE 18

2.7 Diaphragm Walls, Secant Walls, Contiguous Piled Walls

Rigid retaining walls fall into various categories but their singular, primary purpose is to provide lateral ground support prior to the main excavation being carried out.

They are placed into the ground prior to the commencement of bulk excavation. Each variant performs a similar function but as individual methods, their use is dependent on ground conditions and the specific structural requirements of the design.

2.7.1 Diaphragm Walls (DWalls)

SLIDE 19

Diaphragm Walls are continuous, reinforced concrete walls placed in the ground as individual panels, prior to the excavation.

Construction starts with the casting of guide walls into the ground at the location of the D Wall panels.

SLIDE 20

A slot is dug between the guide walls into the ground between the guide walls using an excavating grab in soft ground or a hydromill excavator in soft ground or rock. The slots are commonly 800 to 1500mm thick dependant on the design of the wall, up to 50m in depth although they can go deeper.

SLIDE 21

These slots are dug to form a panel of typically 3 to 7m in length. During excavation, the slots are filled with bentonite slurry to provide support to the ground and prevent ground collapse of the walls of the trench.

SLIDE 22

Once the panel is complete, a reinforcement cage is placed into the panel and this is then filled with concrete using a tremie pipe at the base of the panel.
The introduction of the concrete displaces the bentonite allowing it to be pumped into tanks for future use. Subsequent and adjacent panels are then constructed to form a continuous wall.

SLIDE 23

Once the wall is complete and the required concrete strength attained, excavation inside the wall can proceed with further support from lateral propping and anchoring if and when required as the excavation progresses to depth.

2.7.2 Secant (bored pile) Walls

SLIDE 24

Secant walls are essentially interlocking piles placed into the ground prior to bulk excavation.

The sequence of construction is as follows.

Guide walls are constructed to set out the position of the secant pile wall.

There are several different ways of creating the piles dependant on the ground conditions but a common method is to install a casing into the ground, and then an auger cuts and removes the soil from within the casing to form a primary borehole. The soil surrounding the borehole is supported by the casing.

Concrete is then poured into the borehole to form the primary bored pile and the casing extracted. This process is then repeated adjacent to the existing bored pile but leaving a space between the two of slightly less than the pile diameter.

Next the auger cuts into and removes the remaining soil between the two primary piles to form a secondary borehole. The secondary borehole therefore intersects with the adjacent primary bored piles. A steel reinforcement cage is then placed into the secondary borehole which is subsequently filled with concrete to form the secondary bored pile.

The sequence of primary and secondary bored piles is repeated until the required length of the piled wall is complete. Bulk excavation can then take place between the walls with further support from lateral propping and anchoring if and when required as the excavation progresses to depth.

2.7.3 Contiguous (bored pile) Walls

SLIDE 25

Contiguous walls are a series of individual piles placed into the ground allowing for lateral space between the piles.

These piles can either be cased or non-cased depending on the ground condition. The individual pile can be installed in the same way as that for individual secant piles.

3.0 METHODS OF CONSTRUCTION

SLIDE 26

Although the choice of construction methods to be used on Metro North will be by the appointed Infra Co, the RPA has undertaken assessments of the suitability of established methods for the underground works and has produced reference designs and outline methods of construction.

I will now describe the possible construction of some of the typical Underground Elements of Metro North

3.1 Mined tunnels

Mined Tunnels including the crossover caverns Located just north of St Patricks Shaft and St Stephens Green as well as the loop tunnel could be constructed as follows.

SLIDE 27

As described previously Drill and Blast techniques will be used to break the rock over suitable lengths in the order of 1 to 1.5 m advance per blast. By reducing the length of the blast the amount of explosive per blast is reduced. Following the blast the tunnel will be ventilated to remove gases produced by the explosives by diluting the atmosphere with clean air pumped in from the surface.

The broken rock will then be loaded by excavator into dump trucks and removed from the tunnel.

Temporary Support in the form of Sprayed concrete, and rock bolts will be applied. The excavation and support cycle will be repeated until the tunnel is complete.

A waterproof lining will then be applied to the profile of the tunnel and a permanent concrete lining cast using shutter to obtain the final shape of the tunnel.

3.2 Cut & Cover Tunnels

SLIDE 28

The Cut and Cover technique is construction method widely applied in both urban and rural tunnelling projects.

On Metro North, cut and cover tunnels are envisaged being constructed between DCU and Ballymun Stop and from here to the Northwood Portal.

The ground here is a mixture of made ground and Dublin boulder Clay and is suitable of excavation with hydraulic excavating equipment.

The method most suitable for Metro North is known as bottom up construction and consists of firstly installing a rigid retaining wall into the ground, in this case secant piles. The ground is then excavated between these retaining walls with temporary propping or anchoring to the walls being installed as required.

Once the excavation has reached the required depth a steel reinforced concrete base slab will be cast, followed by the side walls and the roof slab.

The ground above the roof slab will then be backfilled and the surface re-instated.

3.3 Top-Down Stop Construction

An alternative method to bottom up is Top-down construction. This is achieved by constructing the permanent underground structure in stages as the excavation between the temporary retaining walls proceeds to depth.
The retaining walls are installed prior to excavation as previously described.

SLIDE 30

The first stage excavation progresses to just below the roof slab level.
The roof slab is then constructed providing support across the excavation and the ground can subsequently be backfilled and reinstated if required leaving access shafts.

Thereafter excavation can proceed downwards to the next floor of the underground structure with temporary support being applied as required.

The floor slab will then be cast and the cycle of excavation and support repeated until the bottom of the box is reached.

A Base slab is then cast and the side walls are constructed.

3.4 Stop Box Construction

SLIDE 31

The stop boxes or underground stations vary in size and shape due to the local constraints in which they are to be constructed, as well as local geological conditions. They will either be constructed fully within retaining walls or where competent ground exists at depth partly in retaining wall and partly using sprayed concrete and rock bolts

Either the Bottom Up or the Top down Method can be used to construct the Stops.

The retaining walls are firstly installed in the ground, either as secant piles or diaphragm walls and toed into the rock. The ground will then be excavated until rock is reached with internal propping or anchoring being installed as required. On reaching the rock, excavation will continue with shotcrete and bolts being applied to the side walls of the excavation as the box is deepened. On reaching the bottom of the excavation the base slab will be cast and then the internal structure cast from the bottom up until finally the roof slab is cast and the ground above the Stop re instated.
Excavation will be aided in the rock by the use of splitting, impact hammer or drill and blast methods.

3.5 Bored Tunnels

SLIDE 32

Tunnel Boring machines or TBMs are bespoke machines used to excavate tunnels with a circular cross section through a broad range of materials.

They are capable of excavation through a range of ground from hard rock to sand. Tunnel diameters can range from one meter ‘up to the current maximum diameter of 19 meters.

For metro north the proposed TBM’s are approximately 7 meters in diameter.

TBMs are used, as an alternative to drill and blast methods (D&B) in rock and conventional 'hand mining' techniques in soil.

A TBM has the advantage over these methods by limiting disturbance to the surrounding ground mass and thus reducing settlement at surface as the tunneling process is relatively continuous with little time incurred when the surrounding ground is left unsupported. This makes Tunnel Boring machines suitable for use in heavily urbanized areas where settlement is an issue.

They also provide superior production rates of advance when compared to other tunneling methods.

TBMs typically consist of one or two shields, which are basically large metal cylinders, in conjunction with trailing support mechanisms. At the front end of the shield is a rotating cutting wheel often referred to as the “cutting head”

Behind the Cutting head there is a set of hydraulic jacks or rams which push the TBM forward off the previously erected ring or tunnel lining. In this way the TBM advances and can be steered along the tunnel alignment by varying the stroke length of the individual rams.

TBM are large machines commonly over 100m in length and contain equipment required for the tunneling process located in gantries behind the shield.

These include muck removal systems, control rooms, generators and lifting gear for the transport of the precast segments to the ring build area.

Power, compressed air, water and grout are supplied to the machine along cables and pipelines fixed to the completed tunnel lining behind the gantries.

Excavation is carried out at the front end of the machine by a cutting wheel that typically rotates between 1 to 10 revolutions per Minute cutting the rock face into chips or simply excavating soil. This is known as the “excavation cycle”. The revolution speed and rate of tunnel advance is in part, dependent on the size of the tunnel bore and the geological strata being excavated. It is anticipated that on average, each TBM will advance 15 m per day producing approximately 600m3 (or 1200 tonnes) of material.

Following excavation, the muck falls onto a conveyor belt system and carried out of the tunnel to the surface where it is loaded into trucks and taken to a tip site.

For Metro North the main disposal site is at the depot.

For Metro the Tunnel will be permanently supported by a precast concrete lining.

The lining consists of individual segments put together to form a ring. The segments are placed during what is known as the “ring build cycle”. For water tightness rubber gaskets are incorporated into each of the segment sides and ends.

A keystone segment may be incorporated into the ring geometry to “lock” the ring together and tapered segments may be used to facilitate building through curved alignments.

Following the ring build, any voids between the extrados of the ring and the surrounding strata are filled with grout to limit ground movement and water ingress.

START Video at 1min 55 seconds

Dublin Metro North is particularly challenging as it is to be constructed beneath existing buildings in an historic city through varying ground conditions.

The majority of the tunnel will be constructed within mainly good limestone rock strata but between Mater and O’Connell Bridge a section of the tunnels will be constructed within poorer ground conditions and the machine selected by the contractor will have to be able to adapt to these ground conditions.

In this poorer ground it is important to minimise over excavation or face loss which leads to settlement on the surface , which in turn can lead to damage to buildings and structures.

Reducing face loss is achieved by the introduction of positive face control to maintain soil pressure. Two types of machine are commonly used.

- Earth Pressure Balance (EPB),
- Bentonite Slurry (BS)

Both EPB and BS machines could possibly be used on Metro North and would be the preferred methods over open face tunneling in these areas of poor ground conditions.

STOP Video at 1 min 55

The term 'Earth Pressure Balanced' refers to the operation of the machine whereby the excavated ground coupled with conditioning agents are pressurised in the chamber behind the cutter head to balance the pressure of the ground and water in front of the machine. This ensures that ground surface settlement is kept to an absolute minimum

A screw conveyor removes the fluidized muck behind the cutter head and in front of the "pressure bulkhead". The screw conveyor's speed and discharge rate is controlled by the operator and is used to control the pressure at the working face and match the muck discharge rate to the advance rate of the EPBM.

Bentonite slurry machines work on a similar principle by injecting bentonite slurry into the chamber to maintain pressure and then the excavated material is pumped out of the tunnel to the surface.

Many hundreds of kilometers of tunnel have been successfully excavated beneath cities and although Dublin does have some areas of challenging ground conditions the technology and experience exists to overcome this challenge.

4.0 CONCLUSION

SLIDE 35

The presentation provides an outline of the various common techniques that are available to successfully build metro north. Each method requires its own expertise and is a subject in its own right.

Metro North represents Ireland's most significant engineering challenge to date. This challenge can be met and executed using standard methods and techniques which have been tried and tested on similar metro projects across the world.

This concludes my evidence.

Thank you for your time.

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