CANOPY RESEARCH AND DEVELOPMENT

END OF COMMISSION REPORT

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Highways England

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TABLE OF CONTENTS

APPENDICES

EXECUTIVE SUMMARY

This report records the activities undertaken by WSP | Parsons Brinckerhoff (WSP|PB) in relation to the Canopy Research and Development CDF PC 10017 commission for the Air Quality team of Highways England.

The primary aim of this commission was to investigate the feasibility of different types of canopy and barrier type structures that are considered by Highways England to have potential for improving air quality near busy roads. Three different types of structure were investigated:

- A barrier with a cantilevered roof extending over the road;
- A canopy type structure with an open section in the middle for ventilation; and
- A fully enclosed canopy type structure.

Initial research included a review of existing legislation relating to air quality and scientific literature on the improvements to air quality that structures can provide. In addition, a number of existing structures around the world were researched.

Concept designs have been produced where we have attempted to produce efficient, constructible designs. The solutions we have proposed are all thought to be feasible in terms of structural efficiency, constructability, and on-going maintenance costs. Cost estimates for these designs have been provided, and Table 1 below shows these costs for the base cases of steel frame, timber walls and Perspex roof compared to the figures found during the initial research phase of the project. Estimated costs of these structures are in line with the range established from various sources.

STRUCTURE TYPE	ESTIMATED COST FROM CASE STUDIES	ESTIMATED COST OF WSP|PB CONCEPT DESIGNS
Cantilever Barrier	£5 million/km to £13 million/km (on one side of the road)	£21.7 million/km on both sides of the road or £10.9 million/km on one side of the road
Partially Enclosed Canopy	No structure studied is directly comparable to estimate a cost however it is expected that a significant saving can be made over the fully enclosed canopy.	£31.1 million/km
Fully Enclosed Canopy	£9 million/km to £77 million/km	£46.2 million/km

Table 1. Summary of estimated cost of structures

A range of costs exist around those presented in Table 1 depending on the combination of materials selected for wall or roof construction.

The designs are generic and are suitable for a wide range of situations on the strategic road network. Refinement of the designs for a more defined set of criteria will likely lead to a reduction in the estimated cost which may make the provision of a canopy type structure more economically viable.

It is recommended that if further work is to be undertaken, the next steps would require Highways England to determine the design criteria and specific site conditions to be used for a refined design, and to use Computer Fluid Dynamics (CFD) modelling techniques to estimate the possible air quality improvement of different structural forms.

1 INTRODUCTION

1.1 INTRODUCTION TO AIR QUALITY ISSUES FOR HIGHWAYS ENGLAND

The Highways Agency has recently moved from being an executive agency of the Department for Transport to a government-owned company with responsibility for managing the core road network in England through the Infrastructure Act 2015. A number of key documents have been published highlighting how the Department for Transport and the new company intend to operate. Key publications include:

- Road Investment Strategy; for the 2015/16 –2019/20 Road Period;
- Highways England Strategic Business Plan 2015-2020; and
- Highways England Delivery Plan 2015-2020.

Section 9.3.4 of the Highways England Delivery Plan 2015-2020, titled "*Environmental compliance risk*", contains the following statement:

"Legally binding limits for some pollutants are set in EU Directives. The UK and most other Member States are struggling to comply with these in many urban and roadside locations, and there remains a significant risk that our road schemes may be delayed as a result of their air quality impacts. This is because the additional vehicle movements they help facilitate often lead to a worsening of air quality in the immediate vicinity. We will seek to mitigate this, including working with local authorities to support their own initiatives and look for other solutions to improve air quality."

Reading this section in association with the other headings in this chapter on "*Managing risk and uncertainty*", indicates that the ability to deal with air quality issues is recognised as one of Highways England's top four risks in association with;

- Changes in priorities, requirements or budgets;
- Macro-economic factors including demand risk and inflation risk; and
- An ageing asset.

With this in mind, Highways England has implemented a number of studies investigating ways to improve the air quality near roads. This study is part of this work.

1.2 BACKGROUND TO THIS COMMISSION

Highways England's Air Quality team presented a research and development tender opportunity to the consultants on the Collaborative Delivery Framework. The brief associated with the tender is attached as Appendix A.

The objectives of the commission are to:

- Investigate how a Canopy (or tunnel type structure) could be built economically and could be constructed over both carriageways of a motorway.
- Produce a high level design of the structure providing high level costs for its construction, maintenance and decommissioning.

The anticipated areas of work and investigation were listed as being:

- Literature review and an assessment of the effectiveness of different structure types;
- Produce outline designs of the main structures options that would meet the objectives of the canopy/overhanging barrier and meets the construction requirements for a structure built on Highways England's network;
- Provide cost estimates for the construction of the structure per kilometre;
- Consider lifecycle costs including maintenance and decommission of the proposed structures;
- Produce a Structures Options Report listing the main design proposals; and
- Produce a report detailing the findings of the assessment, including recommendations for any approach and costings for all proposed options.

The contract was awarded to WSP|PB on 16 September 2015 subject to a standstill period, based on the methodology submission and a financial offer. A contract start date of 29 September 2015 was implemented and the inception meeting took place on 13 October 2015.

2 AIR POLLUTION ISSUES NEAR ROADS

The purpose of the commission, as set out in the objectives in the previous chapter, relates to a structural solution to mitigate air quality problems near roads. However, to understand solutions, we must first understand what pollutants are, how they behave, and the relevant legislation that can be applied to the environments where air pollution occurs. Air quality legislation sets out maximum concentrations of pollutants in certain locations – residential properties, schools, and hospitals for example.

Whilst a structural solution may provide mitigation for one set of affected parties (for example, those living close to a major road route) through improvements in their air quality, it is critical that the impact on other parties is also considered. For example, a canopy over a highway will likely improve the air quality adjacent to the road, however, the air quality at the opening the canopy and within the canopy will likely be much worse. As such, the health and safety of vehicle drivers and maintenance workers within the canopy need to be considered along with people who may find themselves at the openings of the tunnels.

As noted, the purpose of this commission is to investigate mitigation of the impacts of air pollution from motorways. Highways England is most interested in potentially harmful pollutants emitted from the exhaust of vehicles using their strategic road network. The most significant pollutants are oxides of nitrogen (NO_x) – particularly nitrogen dioxide (NO_2) and Particulate Matter (PM_{10} and $PM_{2.5}$), as these are the pollutants that are most likely to breach the air quality standards and objectives. Further information is included in Appendix B.

2.1 EUROPEAN UNION LEGISLATION

The key European Union documents regarding the management of air quality are:

- Air Quality Directive 2008/50/EC
- The Air Quality Standards Regulations 2010

Full details in relation to these pieces of legislation are contained in Appendix C and the current position regarding meeting EU Legislation is provided below.

Air pollution limits for NO_2 are regularly exceeded in 16 zones across the UK, namely: Greater London, the West Midlands, Greater Manchester, West Yorkshire, Teeside, the Potteries, Hull, Southampton, Glasgow, the East, the South East, the East Midlands, Merseyside, Yorkshire and Humberside, the West Midlands, and the North East. Air quality improvement plans estimate that for London, compliance with EU standards will only be achieved by 2025, which is 15 years after the original deadline. The estimated date of compliance is 2020 for the other 15 zones.

The UK is therefore in breach of its obligations under the Directive. The European Commission sent a letter of formal notice regarding the breach of this Directive in February 2014 (European Commission Press Release) giving the UK two months to respond. Following this, the UK was required to draw up strict plans to reduce the UK's high levels of NO_2 with submission no later than 31 December 2015, and could face fines of up to £300m from the European Commission.

It is noted that The UK Government published a plan on 17 December 2015 which set out local, regional, and national level actions needed to:

- improve the UK's air quality;
- reduce health impacts; and
- fulfil our legal obligations.

This was in a document titled "*Air quality in the UK: plan to reduce nitrogen dioxide emissions*" last updated on 18 January 2016. It set out the air quality plan to meet the UK's goals of improving air quality and public health, and how to fulfil the legal obligations to achieve nitrogen dioxide limit values in the EU Ambient Air Quality Directive (2008/50/EC).

2.2 UK LEGISLATION

In the UK, the key documents regarding the management of air quality are:

- The Air Quality Strategy for England, Scotland, Wales and Northern Ireland (Volumes 1 and 2) July 2007;
- The Air Quality (England) Regulations 2000;
- The Air Quality (England) (Amendment) Regulations 2002;
- The Air Quality (Wales) Regulations 2000;
- The Air Quality (Wales) (Amendment) Regulations 2002;
- The Air Quality (Scotland) Regulations 2000; and
- The Air Quality (Scotland) (Amendment) Regulations 2002.

Full details in relation to these pieces of legislation are contained in Appendix D.

2.3 LEGISLATION REGARDING AIR QUALITY IN TUNNELS

On the basis that the commission is to look at canopy or enclosed/tunnel type structures, we have reviewed the legislation governing air quality in tunnels. While there is a variety of guidance and standards available, the legal situation regarding air quality standards within tunnels is less well-defined than for residential areas. Details are contained in Appendix E.

There is no obvious legislation for air quality in tunnels, except that which is inferred from the Air Quality (England) (Amendments) Regulations 2002, and Health and Safety legislation for public spaces or a place of work for maintenance staff. It is noted that the Air Quality regulations do not cover drivers of the vehicles which may be using the Strategic Road Network (SRN). The advice provided by the British Tunnelling Society is that Control of Substances Hazardous to Health (COSHH) Regulations should be applied. These require that where exposure to a harmful substance cannot be avoided, the exposure must be adequately controlled using the prescribed eight principles of good practice, including;

- Minimise emissions, release and spread;
- Consider routes of exposure;
- Choose control measures proportionate to the risk;
- Choose effective control options;
- Personal protective equipment;
- Review the effectiveness of controls;
- Provide information and training; and
- New measures, new risks.

Furthermore, if the substance causes cancer, heritable genetic damage or asthma, the exposure level must be reduced to As Low As Reasonably Practicable (ALARP). NO may cause emphysema with symptoms that are similar to asthma; therefore exposure to it requires control to the ALARP standard. The key recommendations by the British Tunnelling Society are as follows:

- Occupational exposure to NO should be as low as reasonably practicable (ALARP);
- Target level of NO should be no greater than 3ppm (8-hour Time Weighted Average (TWA));
- NO levels should not exceed 5ppm (8-hour TWA);
- Peak NO levels should not exceed 15ppm (15-minute mean);
- Measures to eliminate the risk of NO exposure should be considered during all phases of a project;
- NO levels should be monitored and recorded; and
- Health surveillance should be considered.

It is considered by WSP|PB that is it would be reasonable to apply these recommendations on air pollution within the tunnel to the canopy type structures in this report.

2.4 DISPERSAL OF POLLUTANTS NEAR A ROAD

Knowing which emissions are present at a source, the next stage is to explain how they disperse through the air between the pollution source and the receptor.

Exhaust emissions from individual road vehicles depend on fuel type, size of engine, age and maintenance of vehicle, road geometry, engine temperature and driving behaviours. The concentration of a pollutant generated from a road thus varies with location and time.

The dispersion of emissions from road vehicles depends on a number of factors related to the specific conditions at the site such as: wind speed and direction, atmospheric stability, temperature, topography, presence/absence of buildings, vegetation, barriers and other structures. The movement of the traffic itself can also give rise to turbulence that can aid the dispersal of pollutants. Accordingly, the likely concentration of pollutants at a specific receptor is dependent on all the above factors, plus the relative position of the receptor to the road.

The distance of the receptor from the road is a key contributing factor to the pollutant concentration. Figure C1 within the Design Manual for Roads and Bridges (DMRB) Volume 11, Section 3, Part 1: Air Quality Annex C, shown in Figure 1 overleaf, illustrates this effect.

Commercially available software, such as ADMS-Roads (which is Highways England approved) can be used to model the dispersal of pollutants from road schemes, with or without the presence of a barrier. The major drawback of this software at this time is the inability to model non-vertical barriers, or situations where the road is partially enclosed on one side or both. Other products are available in the commercial market place, including ANSYS, which can model different shaped barriers. WSP|PB uses ANSYS extensively to model chimney stacks, micro-climates, heating behaviours within buildings, ventilation within tunnels and so on.

The potential air quality benefits of a barrier or partially enclosed canopy type structures include:

- Encouraging an upwards vertical plume and hence more dispersal opportunities in a greater air volume;
- Diverting the path of pollutants away from receptors through the creation of new channels for wind borne pollutants; and
- Increasing the length of the path from the traffic to the receptors by their presence.

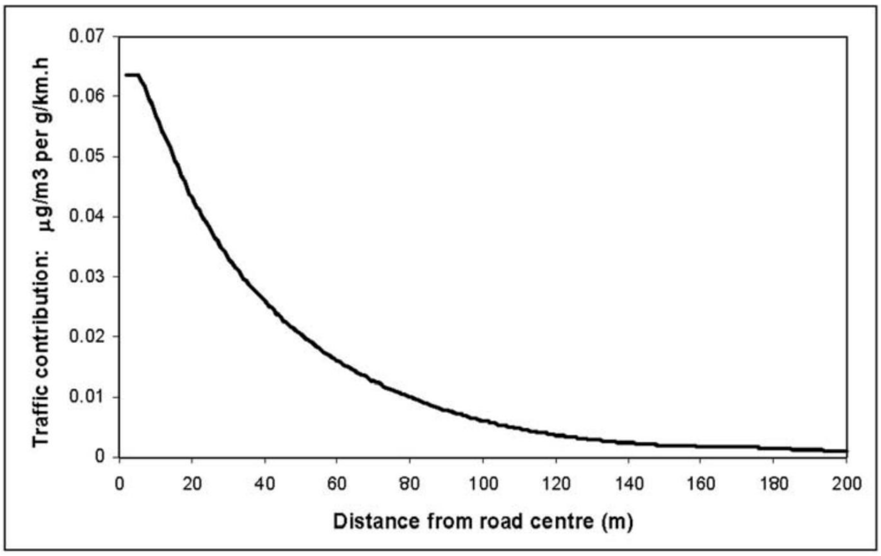


Figure 1. Traffic contribution to pollutant concentration at different distances from the road centre as taken from DMRB

It is noted that in the case of a fully enclosed structure, the pathway for pollutants to receptors is fully cut off and the pollutants would be taken to the structure entrance/exit or other points of ventilation for subsequent treatment or direct release.

Despite the absence of any pollution dispersal analysis to prove their benefits, Highways England and WSP|PB believe that these structures can offer improvements in the air quality near roads and modelling that validates this will be worthwhile should the cost and constructability on the structures be considered feasible.

2.5 SUMMARY

Legislation governing air quality in the UK is well documented and is currently being breached by the UK Government in a significant number of regions within England.

Regulations regarding air quality in tunnels are not well documented and are based around short-term ambient air quality standards defined by legislation. Guidance is available from The British Tunnelling Society relating to health and safety aspects of the air quality in the environment created in tunnels, noting that nitrous oxide is a more important compound to monitor in such an environment than in free air situations.

The modelling software ADMS-Roads, used to assess the impact of traffic on receptors, can model a vertical barrier, but not non-vertical barriers or partially enclosed canopy type structures. More expensive CFD-based software such as ANSYS can model such structures, but the work may be more be time-consuming and costly. However, there is reason to believe that these types of structures can offer improvements to air quality near roads, and modelling validating this will be worthwhile should the cost and constructability of the structures be considered feasible.

3 PRELIMINARY RESEARCH

We have undertaken a review of scientific literature relating to current research and have also researched existing barrier/canopy structures across the world.

The most significant study on this topic is that of the Dutch Air Quality Innovation Programme which looked at numerous options and structures to improve air quality near roads. Most other scientific studies fall into two categories; theoretical studies using Computational Fluid Dynamic (CFD) and practical studies based on field testing. Most studies focus on vertical barriers.

A number of existing structures from around the world have been studied to examine the structure form, cost, benefits and other features. Most structures have been built for noise mitigation rather than air quality improvement; however, we believe that they would still provide air quality improvements.

For baseline cost comparison, we have also investigated the cost of a cut and cover, as this is considered an option that would be fully effective in eliminating air pollution in areas near busy roads.

3.1 THE DUTCH AIR QUALITY INNOVATION PROGRAMME

Figure 2. Covers of: the summary of the programme (left), an example workstream report (middle) and the Scientific Board Review report (right)

A substantial programme of research relating to innovative methods to control air quality near highways (including structural solutions) was carried out in the Netherlands. The Dutch Air Quality Innovation Programme[1] (Figure 2, left) has reported on the following workstreams:

- Optimisation of noise barriers;
- Roadside vegetation;
- Road surface cleaning;
- Canopies and air treatment;
- Catalytic coatings; and
- Dynamic Traffic Management (DTM) and air quality forecasts.

Each of these workstreams has produced a summary report[2] (Figure 2, centre) and an implementation report, in Dutch. There has also been a Scientific Board Review report[3] (in English, Figure 2, right). It presents the findings of an independent scientific board whose purpose was to provide advisory and reviewing functions and to act as a conduit to and from the international research community. This report provides a useful summary and critique of the Dutch programme.

For the purpose of this study, the most relevant workstreams are related to the use of structures: the optimisation of noise barriers and the use of canopy structures. These are reviewed in this section. Other workstreams that are not specifically related to structural solutions, but could potentially be considered in combination with structural solutions, are discussed in Appendix F of this report.

OPTIMISATION OF NOISE BARRIERS

This workstream from the Dutch study considered the use of noise barriers and investigated the potential air quality benefits of the barriers. The principle under investigation was how much the barriers would reduce pollution concentrations behind the barrier by diverting the flow of the air pollution and through the development of a wake region.

It also considered the potential optimisation of these barriers through the use of alternative materials and technology.

A variety of noise barrier designs of varying geometry and materials were considered, as illustrated in Figure 3.

Figure 3. Image from Dutch study of vertical barrier assessment on air quality

Location in the world	Netherlands
Primary purpose for the work	Part of a study to improve air quality near roads. This workstream considered the potential use of roadside noise barriers for air quality purposes.
Air quality benefits assessed?	The study investigated the impact of eight types of noise barriers on the concentrations of NO_x, NO_2 and particulates on air quality at different distances behind the barrier by measuring concentrations. A 100 metre length of barrier was used in a rural setting, with a vertical profile positioned approximately eight meters from the nearest lane marking of the carriageway; see Figure 3. The results generally indicated an improvement in air quality was possible behind the barrier.
Materials used/suggested?	A variety of materials including glass, a screen of vegetation, a screen with titanium dioxide coating, a (partial) porous screen, a screen with active filter, a screen with t-top and a screen with a combination of the above.
Cost	No cost increase on the basis that the provision would be for noise reasons anyway. The cost per kilometre was €0.825 to €5.0 million at Dutch prices which equates to £1.2 to £6.5 million at 2015 UK prices.
Buildability issues?	None
Health and safety issues associated with the proposed provision or its maintenance	None

CANOPIES AND AIR TREATMENT

The Dutch study also looked into the feasibility of building light weight canopy structures that enclose the highway and prevent vehicle emissions from reaching nearby receptors. It also considered what could be done to help the high concentration of pollution within the canopies and at their openings.

Figure 4. Illustration of an example enclosed canopy solution from DHV/NIO Architects

To consider the feasibility of building light weight canopies over the road, several companies were challenged to produce designs that would satisfy loading and safety provisions and a design life of 30 years. A typical example is shown in Figure 4. The resulting designs were estimated at costing €6 to €65 million per kilometre. The lower cost estimates didn't include engineering time. Table 2 below summarises the proposals and the estimated costs, as well as what we estimate the cost would have been in GBP in 2015.

DESIGNER ROOF	TYPE	COST € (MILLION/KM)	COST £ (MILLION/KM, 2015)
DHV / NIO	Concrete with ribs	65	64.6
TU Eindhoven /Booghal	Steel trusses with foil	6*	5.9
Bosvariant / TNO	Glass greenhouse	7*	6.9
Cl Structures / Sprung / Hartman, Dura Vermeer / Advin	Aluminium construction with cloth	12	11.9
Lammerts van Bueren	Tents (excluding some construction costs)	6.6*	6.5
Movares	Cold Curved glass	20	19.9

*Excluding engineering time.

Table 2. Typical estimated costs associated with canopy/tunnel options from Dutch study

Options for cleaning the air in the canopies such as electrostatic filters, bag filters and wet scrubbers were also investigated. The most promising of these was the electrostatic filter concept. This was trialled in a tunnel and found to reduce PM_{10} level by around 10%. While promising, this technology requires further testing and development.

Location in the world	Netherlands
Primary purpose for the work	Improving air quality near roads
Air quality benefits assessed?	Yes, specifically, with local air quality being greatly improved away from the portals. However, air quality near the portals worsened. The effect on road surface deposition is unclear.
Materials used/suggested?	Many materials were considered in the study including steel, concrete, aluminium, glass, fabric and foil.
Cost	€6 to €65 million per kilometre at 2010 Dutch prices, which equates to a price range of £6 to £65 million per kilometre in 2015.
Buildability issues?	Road closures would be required during construction.
Health and safety issues associated with the proposed provision or its maintenance	Levels of air pollution inside the structure would need to be managed with respect to the health and safety of maintenance staff. Enclosing the highway could also affect driver safety in the event of an accident or a fire.

3.2 STUDIES USING COMPUTATIONAL FLUID DYNAMICS (CFD)

BOWKER ET AL (2007)

This study[4] analysed the effects of sound barriers on local air quality at a site in Raleigh, North Carolina, USA.

They used a computational model which was verified with measurements taken at the site. The study suggests that the presence of noise barriers could have a significant beneficial effect on air quality up to several hundred metres from the road. Figure 5 shows a typical output from this study.

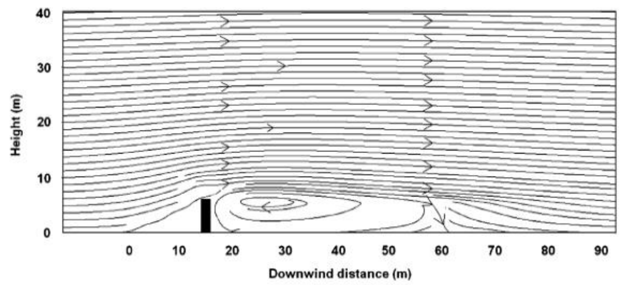


Figure 5. Illustration of the airflow around a barrier in crosswind conditions from Bowker et al (2007)

Three effects were noted for crosswind conditions:

- The plume was lifted over the barrier, simulating an elevated source.
- A recirculation wake region occurred in the lee of the barrier, with little pollution falling into this region, thus improving air quality.
- When the elevated plume encountered other obstacles like trees or buildings, further mixing occurred that improved dispersal and reduced concentrations further.

HAGLER ET AL (2011)

This paper[5], uses a 3-D CFD model in combination with existing wind tunnel test data to investigate the effect of a roadside barrier on near road pollution. Typical outputs are shown in Figure 6.

Key findings:

- At 20 metres from the barrier, the study found that gaseous pollution was reduced by 15% to 61% for barrier heights varying from 3 metres to 18 metres.
- Pollution levels on the road side of the barrier were increased by a factor of 1.1 to 2.3.
- If there were other sources of emissions on the leeside of the barrier, these were found to be magnified by the barrier.
- There were increased pollution levels near the end of the barrier.
- The wind direction also played a key role in the predicted results.

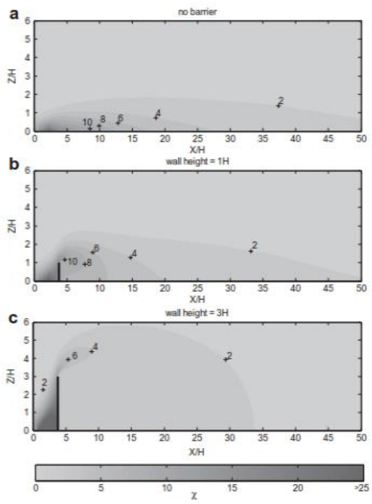


Figure 6. Contour plots of concentration levels behind barriers of different heights from Hagler et al (2011)

STEFFENSA ET AL (2013)

This paper[6] considers different numerical approaches to modelling the effectiveness of a solid vertical barrier on downwind air quality, including at the leading edge of the barrier, where higher concentrations are possible, as seen in Figure 7.

The paper concludes that, in general, a barrier will improve air quality compared with no barrier, and makes recommendations for methods of modelling the influence of local parameters on the effectiveness.

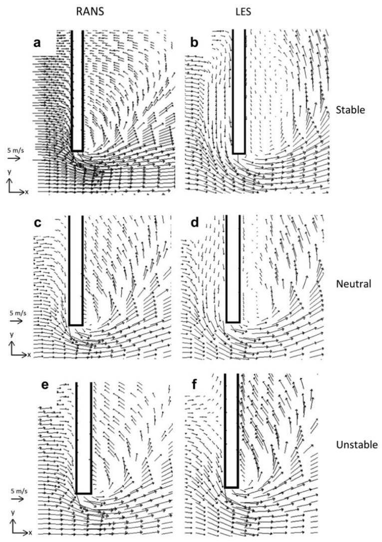


Figure 7. Plan view of the flow at the leading edge of a solid barrier under different conditions and using different CFD models.

BRECHLER ET AL (2014)

This modelling study[7] also investigated the effect of barriers which were positioned either as a single 3 metre barrier on either the upwind or downwind side of a highway, or on both sides. These results suggested that barriers could improve environmental conditions, as can be extrapolated from Figure 8. The study also concluded that barriers on both sides of the highway provide the most effective solution, however the use of one barrier located on the upwind side resulted in an almost identical result at lower cost. A single barrier on the leeward side was less effective.

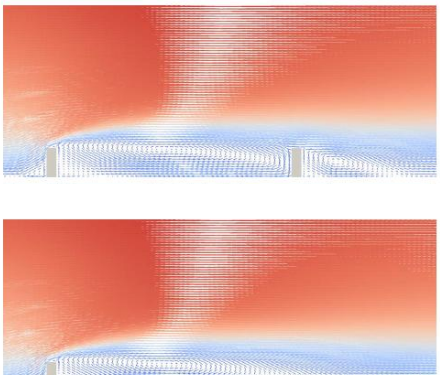


Figure 8. Plots from Brechler et al (2014) illustrating flow around barriers on both sides (top) and one side only (bottom) of the highway

Due to the variability of wind direction, it is unlikely to be possible for a single noise barrier to be placed so as always to be upwind of a road. However, a key objective of concern is the long term or annual mean objective for pollutants such as NO_2. Depending on the characteristics of a particular location, positioning a noise barrier on the upwind side of a road for the prevailing wind direction may have a similar effect to having barriers on both sides for the annual mean objectives.

3.3 STUDIES USING FIELD TESTING

BALDAUF ET AL (2008)

A further study of the effects of a noise barrier in Raleigh, North Carolina[8] on CO and PM concentrations using monitoring found a decrease of between 15% and 50% of both CO and PM concentrations behind the barrier in crosswind conditions. Typical output is illustrated in Figure 9.

However, the study also found a small number of instances (depending on wind direction and other factors) where the concentrations behind the barrier could be higher than with no barrier.

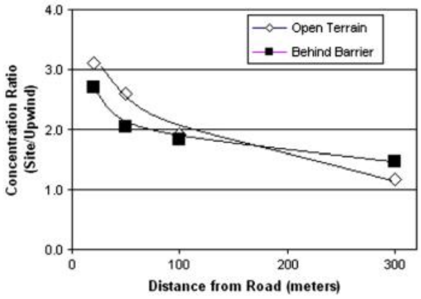


Figure 9. A plot from Baldauf et al (2008) illustrating concentration levels with and without a barrier

FINN ET AL (2010)

This paper[9] documents field measurements of an atmospheric tracer released near a barrier to simulate roadway emissions. The barriers were constructed from straw bales in Idaho, USA. A typical set up is illustrated in Figure 10.

The study identified a well-defined recirculation zone in the wake of the barrier with reduced concentrations (with reductions typically in excess of 50%), and an increase in concentrations on the roadside of the barrier, particularly in low wind speed stable conditions.

Figure 10. Photo of testing arrangement and straw bale barrier from Finn et al

NING ET AL (2010)

This paper[10] investigated two highly trafficked freeways in Southern California, and investigated the air quality (particle size, distribution, and concentration) at sites with and without roadside noise barriers for each freeway. The results suggest a "concentration deficit zone" near the barrier, although the pollutants were increased at about 80 metres to 100 metres from the freeway. Background levels were reached at distances of 250 metres to 400 metres as can be seen in the graphical representation in Figure 11.

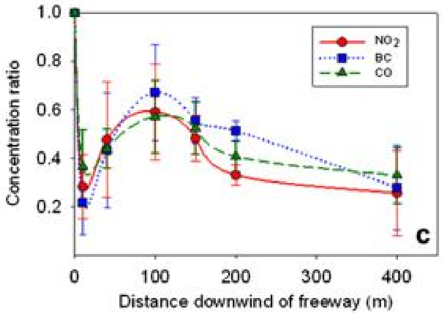


Figure 11. An example concentration plot from Ning et al (2010)

HAGLER ET AL (2012)

Following their 2010 study using CFD modelling technology, Hagler et al[11] went on to publish a further study based around field measurements in 2012. The study reports measurements for three sites in North Carolina USA. The results support the notion that solid roadside barriers may mitigate near-road impact of emissions (see Figure 12), but the potential beneficial effect of vegetation was unclear.

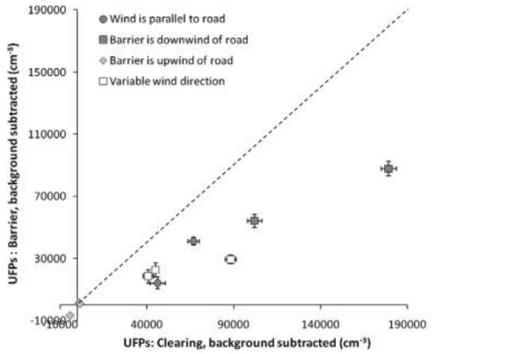


Figure 12. Comparison of concentrations with and without a barrier from Hagler et al (2012)

3.4 OTHER STUDIES

KROON (2010)

This master's thesis[12] considers the feasibility of a glass canopy enclosure for a highway, for the purposes of reducing both noise and air pollution, as illustrated in Figure 13.

The solution considered was developed by Movares. Kroon's thesis considers a variety of socio-economic impacts as well as engineering feasibility issues.

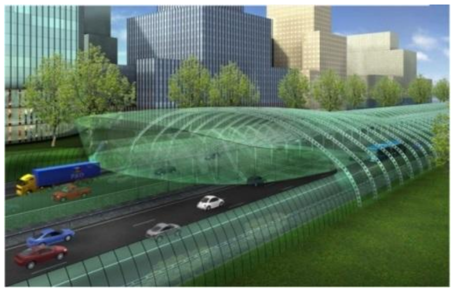


Figure 13. Indicative means of enclosure from Kroon (2010)

Location in the world	Study carried out at Delft University of Technology. Generic solution intended for use in the Netherlands.
Primary purpose for the work	To develop a feasible solution for the environmental effects of road traffic.
Air quality benefits assessed?	The solution presented is an entirely enclosed structure, thus diverting emissions to the ends of the canopy. Innovative methods for cleaning and filtering the air are proposed in order to mitigate air quality issues at the ends of the structure.
Materials used/suggested?	Bendable laminated glass on a steel frame.
Cost	Construction cost estimated at €57 million (approx. £47 million pounds in 2015) for a 715 metre length, including a 30% allowance for "engineering costs, legal dues and unforeseen costs". There is also a socio-economic feasibility analysis including a detailed consideration of a variety of aspects including land usage, effect of noise reduction on property value, beneficial value of emissions reductions.
Buildability issues?	Constraints on available space considered.
Health and safety issues associated with the proposed provision or its maintenance	Driver safety issues have been considered including fire scenarios, and compared with alternative solutions including a tunnel. The anticipated maintenance of the structure and any safety issues are not presented in detail.

BROLIN (2010)

This master's thesis[13] considers the development of a curved barrier in concrete and includes a consideration of both noise and air quality aspects. A typical diagram of what was being proposed is illustrated in Figure 14. However the thesis does not quantify the effectiveness of the curved barrier or the costs.

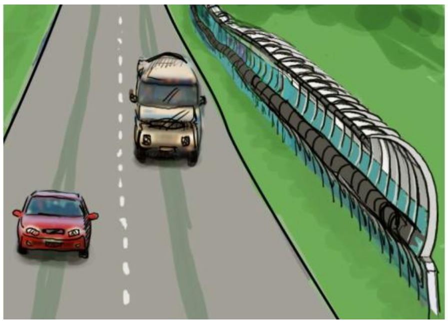


Figure 14. Sketch from Brolin (2010) of the curved barrier product.

VARIOUS OTHER PAPERS

A number of other papers have been reviewed; for example:

- *Modelling air quality in street canyons: a review*[14];
- *Policies and technical guidelines for urban planning of high-density cities – air ventilation and assessment (AVA)*[15]; and
- *Revised air quality action plan interventions*[16].

These provide useful information regarding methods for addressing air quality but are not specifically related to structures.

3.5 CASE STUDIES OF EXISTING STRUCTURES AROUND THE WORLD

HONG KONG NOISE WALLS

In recent years, Hong Kong has been improving the effectiveness of their sound barriers by retrofitting a cranked section of wall that raises the height of the barriers and extends over the road. The purpose of these modifications is to improve the noise blocking performance of the barriers. A photo of these modified barriers is shown in Figure 15. The cranked section at the top of the wall increases the noise shadow and protects high-rise apartments.

Figure 15. Modified noise walls in Hong Kong

We contacted the Environment Protection Department (EPD) of Hong Kong to obtain information regarding the feasibility. A summary of the information received is below.

Location in the world	Hong Kong
Primary purpose for the work	The purpose of the cranked top of the barriers is to enhance their noise mitigating performance compared with straight vertical barriers.
Extent of air pollution containment	Partial containment. We have been provided a recent proposal for a section of road. In this proposal the total barrier heights are 7 metre and the cantilevers extend out at approximately 30 degrees to the horizon by approximately 2 metres. A sketch of the barrier can be seen on the next page in Figure 16.
Air quality benefits assessed?	The EPD have looked at the effects of the barriers on local air quality and concluded they have "no effect". However, the approach taken was to use computer modelling rather than on-site testing. They have informed us that they used the "At Grade" option of the Caline4 model with the height of the road section set equal to the height of the noise barrier. This is a conservative approach as it does not consider the dispersion of pollutants before rising to the top of the barrier.
Materials used/suggested?	Polymethyl methacrylate (pmma) is commonly used as it is transparent and has a high resistance to weather and abrasion.
Cost	The EPD told us that the cost varies case by case subject to types of foundation works required and the current market prices. On the recent example that was provided, the cost of the cantilever barriers (excluding engineering time) was estimated to be HK$25.6 million for 215 metres of barrier. This works out to be approximately £4.7 million/km.
Buildability issues?	None
Health and safety issues associated with the structure or its maintenance	None

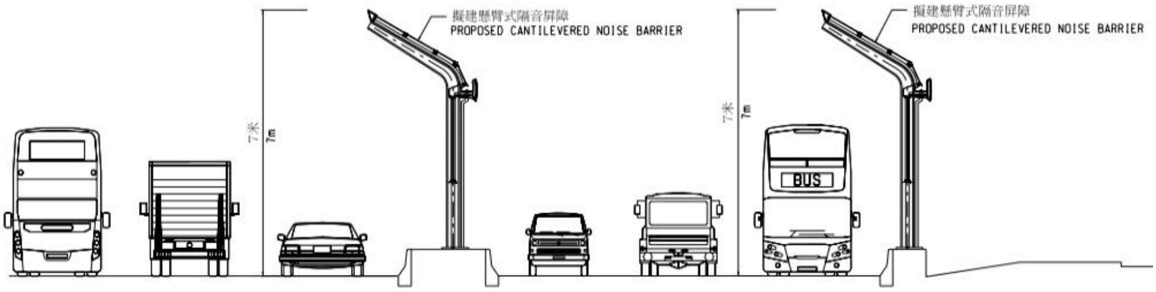


Figure 16. Sketch of cranked barriers in proposal from Hong Kong

The provided proposal also included a section of fully enclosed road and semi-enclosed road. Sketches of these two structures are included below in Figure 17 and Figure 18, below.

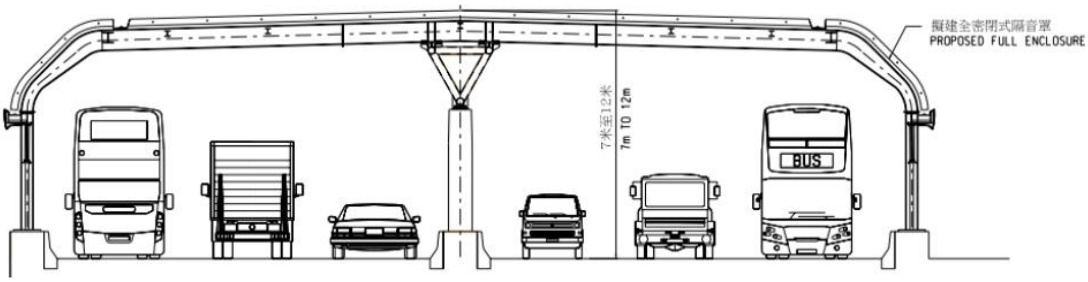


Figure 17. Sketch of fully enclosed barriers in proposal from Hong Kong

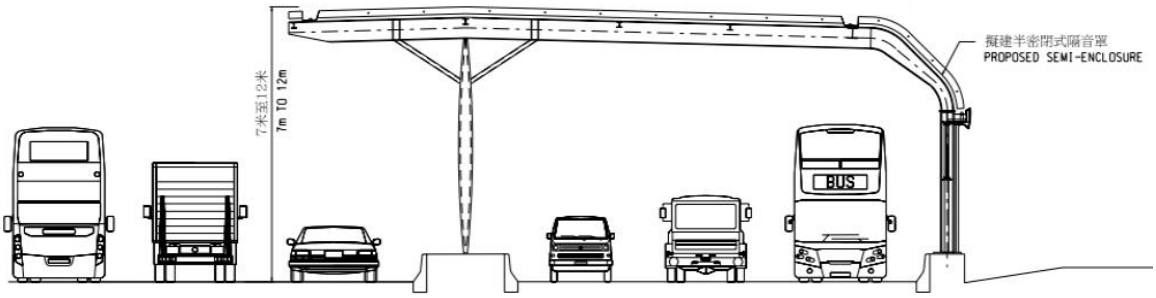


Figure 18. Sketch of semi-enclosed barriers in proposal from Hong Kong

The estimated cost of these structures, excluding engineering time, is HK$111.5 million for 130 metres of fully enclosed barriers, and HK$321.3 for 430 metres of semi-enclosed barrier. This works out to be approximately £77.2 million/km for fully enclosed barriers and £67.2 million/km for the semi-enclosed barrier.

While costs seem high, the proposed location for these structures is along a large, busy road in a built up urban area, and as such, may not be typical of the situations where similar structures could be installed in the UK.

SOUND BARRIER AT WIELWIJK ON HIGHWAY A16

In the mid-1990s, a large curved noise barrier extending out from its support was constructed along the A16 highway near Dordrecht in the Netherlands. Figure 19 shows a photo of this barrier.

Figure 19. Barrier on the A16 Highway in the Netherlands

The highway travels next to the residential neighbourhood of Wielwijk. Some housing estates in this neighbourhood are as close as 10 metres from the road. The barriers were built along with a sophisticated planting scheme in an effort to reduce the noise and air pollution from the highway in the neighbourhood.

To find out more about this structure, we attempted to contact both the architects of this structure (Hans van Heewijk architecten) and the Ministry of Infrastructure and the Environment in the Netherlands (Rijkswaterstaat). We received a response from Rijkswaterstaat. Brief information has also been found on the architect's website. The combined information is summarised below.

Location in the world	The Netherlands
Primary purpose for the work	Noise and air pollution minimisation in the residential area next to the highway.
Extent of air pollution containment	Partial containment. The barriers stand 9.5 metres tall and extend out over two two-car lanes.
Air quality benefits assessed?	Unknown
Materials used/suggested?	Prefabricated concrete columns with steel space frame girder in-between supporting translucent acrylic sheeting.
Cost	26 million Dutch guilders in 1997 for 1km of barrier (approx. £13 million in 2015).
Buildability issues?	Unknown
Health and safety issues associated with the structure or its maintenance	Unknown

MELBOURNE SOUND TUBE

The Melbourne Sound Tube is located on the CityLink highway in Melbourne, Australia. It was installed when the highway was constructed in 1999 to limit noise pollution from the road with relation to a number of high rise apartment blocks. It is also an architectural feature on the highway. The structure comprises a steel arch frame which extends over the entire highway with attenuating cladding attached over the western side of the arch. This can be seen in Figure 20.

Figure 20. Diving through the Sound Tube

Efforts have been made to contact the owners of the sound tube, Transurban, to collect more information regarding its design cost and construction. Transurban however have not been able to direct us to an appropriate person to answer our questions despite our best efforts on the matter. An article on this structure found at http://tollroadsnews.com/news/melbourne-oz-innovative-sound-tube has provided some limited information; a summary of this information is below.

Location in the world	Melbourne, Australia
Primary purpose for the work	The primary purpose of the sound tube was to block noise to three 21 story high apartments block approx. 150 metres from the road. The structure type has also been used an architectural feature for the road and “gateway” to the city.
Extent of air pollution containment	The containment is only partial with only the western side of the tube having cladding.
Air quality benefits assessed?	Unknown
Materials used/suggested?	Steel frame covered with sound attenuating cladding on the western side of the wall.
Cost	AU$5 million in 1999 for the 300m long structure (approx. £3.7 million in 2015).
Buildability issues?	Unknown
Health and safety issues associated with the structure or its maintenance	Unknown

WARSAW SOUND TUNNEL

In Warsaw, Poland there is a recently built sound proof tunnel. This tunnel comprises steel arched frames with a transparent glass and acoustic aluminium cladding. A photo taken looking through the tunnel is shown in Figure 21.

To find out more about this tunnel we have been in contact with our colleagues in Poland who have contacted the architect, Bartłomiej Grotte at Foroom. The information that we have received in summarised in the table below.

Figure 21. View looking through a soundproof tunnel in Warsaw

Location in the world	Warsaw, Poland
Primary purpose for the work	Noise pollution reduction.
Extent of air pollution containment	Full containment.
Air quality benefits assessed?	No.
Materials used/suggested?	A steel frame structure was used with road acoustic aluminium panels (made by Schuette) placed in the lower part of the tunnel walls and transparent glass panels (made by Saint Gobain) used in the upper sections of the tunnel walls and the roof.
Cost	€30 million+VAT for the 1.8km long tunnel, with a varying span of 40 metres to 80 metres (approx. £24 million+VAT for the entire tunnel, or £13 million+VAT per kilometre).
Buildability issues?	The largest buildability issue was matching the tunnel geometry to the changing shape of the road.
Health and safety issues associated with the structure or its maintenance	Fire exits were required to be built along the structure.

BEIJING SOUND TUNNEL

This Chinese sound-proof tunnel has been recently built covering a raised highway that travels over the Beijing Zoo. The purpose of the tunnel is to prevent fauna in the zoo being disturbed by traffic noise. From photos we have found, the structure seems to comprise a steel arch frame and transparent cladding. A photo of this tunnel just prior to completion can be seen in Figure 22.

We contacted our colleagues in Beijing and asked that they do some research for us; however they could not source any more information. As such, we have not been able to collect any cost or constructability information for this structure.

Figure 22. Soundproof tunnel over Beijing Zoo

Location in the world;	Beijing, China
Primary purpose for the work	Reduction in noise pollution.
Extent of air pollution containment	Full containment.
Air quality benefits assessed?	Unknown
Materials used/suggested?	Unknown
Cost	Unknown
Buildability issues?	Unknown
Health and safety issues associated with the structure or its maintenance	Unknown

SOUTH KOREAN SOUND TUNNELS

In South Korea, sound proof tunnels appear to be commonly constructed to address sound pollution issues. We have found South Korean manufactures that produce sound proof tunnels like that shown in Figure 23 below.

We have contacted our colleagues in South Korea who have helped to collect some information for this study. We have also tried to contact Unison eTech Co., Ltd, a manufacturer of sound proof tunnels, but we have not yet received a response. Sangjin Development is another manufacturer of soundproof tunnels, and a typical installation they have carried out is shown in Figure 23. In the table below the figure, we have summarized the information we have obtained from our South Korean colleagues.

Figure 23. Typical soundproof tunnel installed by Sangjin Developments in South Korea

Figure 24. Scaffold arrangement used in South Korea during construction over a live carriageway

Location in the world;	South Korea
Primary purpose for the work	Reduction in noise pollution.
Extent of air pollution containment	Full containment.
Air quality benefits assessed?	Unknown
Materials used/suggested?	Galvanized sheet iron panels and steel beam frames are typical.
Cost	Approx. KRW 400,000/m^2 (approx. £230/m^2; approx. £9.2 million per kilometre for a 40 metre span across road).
Buildability issues?	There is a challenge in constructing the structures on existing roads while causing minimal disruption to traffic and maintaining a safe working environment for workers. Often work needs to be carried out during night under traffic control. One way this has been improved is by using a special supporter (scaffold) as in Figure 24, above. This allows work to happen during the day reducing risk to traffic and workers while allowing traffic to continue to flow.
Health and safety issues associated with the structure or its maintenance	Unknown

3.6 INFORMATION AVAILABLE FROM HIGHWAYS ENGLAND

At this time, the design guidance for the provision of environmental barriers is in HA 65/94 Design for Environmental Barriers (noting that this is an aged publication), contained in DMRB Volume 10, Section 5, Part 1, And HA 66/95 Environmental Barriers: Technical Requirements, DMRB Volume 10, Section 5, Part 2.

The same principles could apply to airtight barriers for air quality control purposes. It is likely that an allowance would need to be made for the fact that no air would pass through the barrier and so a small increase in wind loading factors may be required.

Discussions have taken place with other departments within Highways England in regard to environmental barriers. Information obtained to date is as follows:

1. There is no Category Management group covering environmental barriers at this time.
2. It is not believed that there is an approved list of suppliers at this time.
3. The British Board of Agreements has been contacted for a list of approved manufactures to HA 66/95. Their response was “we do not have any approved manufacturers within this sector (a list of approved manufacturers of environmental fencing to HA 66/95 of Design Manual for Roads and Bridges)”.
4. Anecdotal evidence is that it is difficult for European manufacturers to have their products approved for use on the Strategic Road Networks due to certification requirements.

Discussions with the category management lead have indicated that there is concern with the present end performance specification being utilised on Smart Motorway Programme (SMP) schemes at this time. For example, a 4.0 metre high reflected barrier can be a concrete block wall rather than something more sympathetic in a rural setting. Accordingly, it is understood that SMP procurement is looking into ways of improving the situation. It is noted that this may present an opportunity for inter-discipline inputs in relation to noise, air quality, procurement and category management.

We established contact with the Highways England commercial team in regard to the cost of environmental barriers, and the data obtained at this time includes the following:

- 2.95 metre acoustic barrier with mild steel posts - £260/m
- 4.00 metre acoustic barrier with galvanised steel posts long run - £380/m
- 4.00 metre acoustic barrier with galvanised steel posts short run - £900/m

Cost estimates include an additional £2,200 for 3 metre high barriers and £2,500 for 4 metre high barriers per box out section around apparatus and furniture, where the line of the barrier is required to be broken to accommodate above ground obstructions. Being a difficult activity, the box outs are priced separately. It is understood that the costs are based on design and erect basis and so additional extra overs must be allowed for traffic management, supervision, assurance and so on, if they are being installed as a stand-alone project and not part of a greater scheme.

3.7 CASE STUDY: LUTON BOROUGH COUNCIL

As part of the M1 Junction 10 to 13 scheme, a number of options were investigated to reduce the impact of poor air quality at peak traffic times. The final design implemented was the provision of high vertical environmental barriers on both sides of the carriageway where it passes through the Air Quality Management Area.

The most recent report by Luton Borough Council (their 2014 Air Quality Progress Report, (http://www.luton.gov.uk/Environment/Lists/LutonDocuments/PDF/Environmental%20and%20Consumer%20Services/Pollution/Air%20Quality%20Strategy/2014%20Progress%20Report.pdf) has been reviewed.

At this time, it is difficult to draw conclusions from the data on the basis that it does not extend a significant time past when the barriers were installed and traffic conditions have been variable in the area for a number of reasons. Accordingly, the effectiveness or otherwise of the environmental barriers in relation to local air quality is unproven in this location.

Location in the world;	Luton, UK, adjacent to the M1 in AQMA.
Primary purpose for the work	Noise attenuation with AQ as a potential bonus.
Air quality benefits assessed?	Yes in part linked to Luton AQMA.
Materials used/suggested?	Standard UK environmental barrier construction.
Cost	As related to Highways England data indicated in Section 3.6.
Buildability issues?	Difficulties associated with foundation design fitting into congested narrow verge.
Health and safety issues associated with the proposed provision or its maintenance	None identified.

3.8 COST ESTIMATE FOR A CUT AND COVER TUNNEL

An estimate has been prepared for a cut and cover tunnel to be used as a baseline comparison for the cost for the other structures considered in this study. The cut and cover tunnel structure is assumed to be constructed over the existing strategic road whilst being improved as part of a greater commission; for example, conversion to Smart Motorway. This way, all time-related charges would not be attracted specifically to the cut and cover provision.

The cross section was assumed to be a three-lane motorway for the purpose of the estimate. The structure comprised precast concrete units to speed up construction and reduce the time of carriageway occupation. The assumption was that foundations on each side would be piled with an associated ground beam located 4.5 metres back (so that impact loading was not considered on the wall or roof due to the clearance provision made). A modified vertical concrete barrier in the central reserve was included to provide support to the roof sections. Provision was also allowed for forced air ventilation systems, fire suppression systems, emergency access/egress, lighting, and so on.

The estimate cost for this structure, as calculated by our Quantity Surveying team and based on a detailed brief prepared for them by the rest of the multi-disciplinary team, was £95 million per kilometre.

Other data sources have been looked at in relation to the cost of tunnels in the UK. The A3 Hindhead tunnel (a 70mph dual carriageway, two lanes per direction, bored tunnel) cost approximately £300 million for 1.9km, translating to £155 million per kilometre at 2011 prices, and, expressed as 2015 prices, would equate to £185 million per kilometre. Data from an HM Treasury "Infrastructure Cost review" report (December 2010) estimated a double lane road tunnel would cost up to £100 million per kilometre length of tunnel. This would equate to £122 million per kilometre at 2015 prices. It is assumed that these two figures are all-in and so the impact of land, pavement, side roads, and so on has been taken into account. These costs would not be incurred in the cut and cover enclosure of an existing road, and accordingly the view is expressed that there is a reasonable compatibility between the prices indicated for the worst-case full enclosure.

3.9 CONCLUSION

There is little research, as far as we are aware, that looks at the effects of cantilevered barriers and partially enclosed canopy structures on the effects of air quality. In contrast, the effectiveness of vertical barriers on improving air quality near busy roads has seen significant research in recent years. Results from studies on vertical barriers using both computational fluid dynamics and field testing suggest that there are some benefits on air quality near roads; however, the benefits are variable depending on the specific site conditions. The effectiveness of the barriers seems to increase with height. Placing barriers on both sides of the road appears to be more effective than when they are only placed on one side.

There are a number of canopy and cantilevered barrier-type structures that have been constructed around the world, along with studies that have produced cost estimates for such structures. The structures investigated as part of this study have all been built for sound mitigation rather than air quality improvement; however, we expect that air quality improvements would have occurred and the cost would be comparable to any structure designed for air quality improvements in the UK. Of the structures researched, steel is the favoured building material. Many of these structures are also architectural landmarks. A summary of the cost range of the investigated structures is listed below in Table 3.

STRUCTURE TYPE	ESTIMATED COST (PER KM) FROM AVAILABLE INFORMATION
Cantilever Barrier	£5 million to £13 million (on one side of the road)
Partially Enclosed Canopy	No structure studied is directly comparable to estimate a cost, however it is expected that a significant saving can be made over the fully enclosed canopy.
Fully Enclosed Canopy	£9 million to £77 million
Tunnel	£95 million to £185 million

Table 3. Summary of cost form existing structures and studies form around the world

There is a wide range of costs for the cantilevered and fully enclosed canopies. There may be a number of reasons for this, including such factors as:

- Local labour costs;
- Proximity to steel markets which are over-producing;
- Less restrictive design guides to those expected in the UK;
- With architectural elements included, design fees may be low due to the iconic nature of the structures in the anticipation of repeat business or overseas implementation of the ideas; and

- Different rules in relation to health and safety in design, construction, operations and maintenance.
- Required geometry of the structure such as number of lanes to span, width of shoulder, width of central reserve and the ability to include a central support.

4 POST LITERATURE REVIEW OPTION DEVELOPMENT

4.1 INTRODUCTION

From the review carried out in Chapter 3 above, it is evident that a number of courses of action were open to the project team in regard to air quality mitigation. The purpose of this chapter is to provide the rationale for the decision-making process for the options included in the formal Structures Options Report (SOR).

4.2 VERTICAL BARRIERS

The case for vertical barriers was inconclusive from the work described above. The barrier serves to direct the poorer quality air upwards before it travels towards the receptor and so the height of the barrier and the distance to the receptor are the two critical parameters.

There is a trial being carried out by Highways England on the M62 at this time which will provide information about the buildability of such a structure and the manner in which it behaves. Design and construction stages information was obtained from the Highways England Project Manager along with the Lessons Learnt Log. One of the key items from the log was the need for an appropriate cost estimate to be established inclusive of such costs as design, prelim costs, land fees, risk, traffic management, PSF site/commercial assurances, CDM-C and so on.

Data acquisition and assessment is still on-going and is not reported or commented upon here. Accordingly, WSP|PB was advised not to include a vertical barrier specifically in the Structures Options Report by the Highways England Air Quality team at a meeting held on 29th January 2016. This was on the basis that the team knew that they can be constructed and monitoring work would reveal the behaviour of air flows in the vicinity of the structure.

4.3 OPTIONS TO BE CONSIDERED

With a simple vertical barrier excluded and the commission seeking to investigate the effectiveness of “canopy or tunnel type structures”, consideration was given to options that could feasibly and economically and constructed.

From the literature review in the previous chapter and the structural design knowledge and expertise within the team, WSP|PB concluded that the options to be investigated should be:

- A vertical barrier with an inclined section over the carriageway;
- A cantilevered or portal structure which provide partial enclosure; and
- A structure which provided full enclosure of the carriageways.

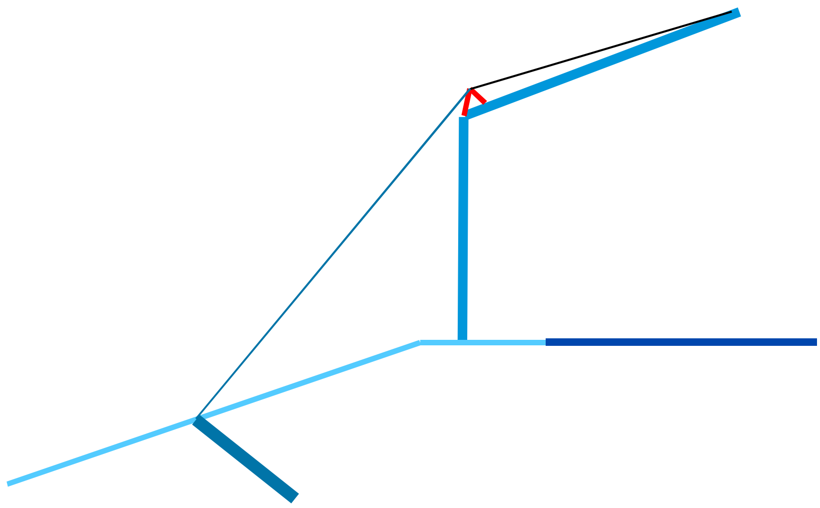
Before seeking agreement of these concepts from the Highways England’s Air Quality Team and progressing into the formal SOR stage, a review of each was carried out and is summarised in the sections below.

4.4 INITIAL CONCEPTS

Thought has been given to innovative ways that each of the structures options to be considered could be built most efficiently while still providing air quality improvements. The initial concepts to be used as a starting point for the SOR are described briefly below.

VERTICAL BARRIER WITH AN INCLINED SECTION OVER CARRIAGEWAY

The sketch below shows the initial concept for the vertical barrier with and inclined section extending over the road. It is thought that by providing a stay, bending moments in the supporting members and foundations could be significantly reduced to produce a more light weight structure than would otherwise be possible.



Typical cross section at frame locations

Frames may be positioned close enough for cladding to span between (similar to a concrete post and panel noise barrier) or the cladding may be able to span between purlins that in turn span between the structural frames. These options will be looked into and decided in the SOR.

A minimum of 5.7 metres vertical clearance will be necessary to avoid the need to design a heavier structure for such impacts. To maximise the probable air quality benefits, it is suggested at this time that the end of the cantilever be located over the white line associated with the Lane 2 and 3 demarcations. This would be the equivalent of some (2.5 metres [verge] plus 3.3 metres [hard shoulder] plus 3.65 metres [running lane]) 9.45 metres of cantilevered length.

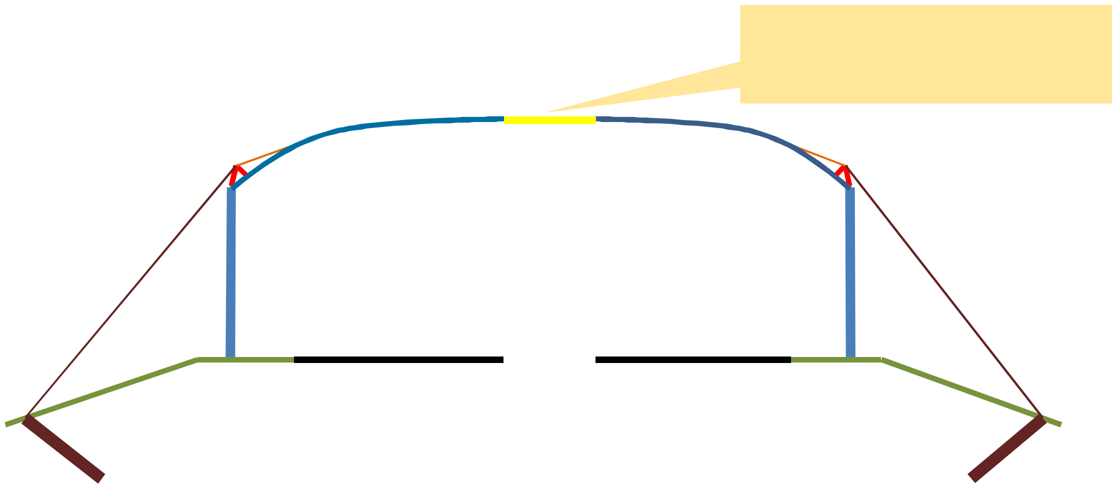
CANTILEVERED/PORTAL STRUCTURE PROVIDING PARTIAL ENCLOSURE

This option is seen as being the natural progression to the inclined provision described above with the minimum height clearance being provided for a greater width of the carriageway. The figure overleaf shows the proposed concept which makes use of the same stayed arrangements described in the previous section to reduce bending moments and thus reduce member and foundation sizes. It is thought that with the extended cantilevers on both sides of the road a compression strut may be beneficial to provide extra stability to the structure.

Frames may be positioned close enough for cladding to span between (similar to a concrete post and panel noise barrier) or the cladding may be able to span between purlins that in turn span between the structural frames. These options will be looked into and decided in the SOR.

The typical amount of coverage across the carriageway is assumed to be the first three lanes, including the hard shoulder. Depending on the overall cross section of the route, the resulting gap/chimney between the structures, if they were on both sides, would be in the order of 2.5 to 9.8 metres, assuming a D2AP or D4M respectively.

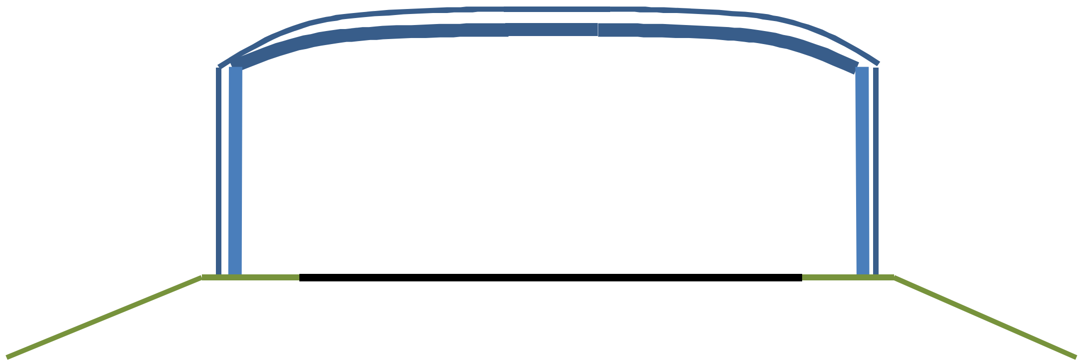
Depending on the road geometry and the require area to be covered , it may be more practical and economical to instead use a portal frame like that describe in the next section and leave a section above the middle of the road without cladding. This will be looked at further in the SOR.



Typical cross section at frame locations

STRUCTURE WHICH PROVIDED FULL ENCLOSURE

It is thought that the most efficient solution for a fully enclosed canopy is a portal frame that extends over the entire width of the road. This is on the basis that portal frames are very structurally efficient and by using pin connections to the foundations, the foundation size will be minimised. It is envisaged that the cladding of the canopy would then be supported on purlins spanning between the portal frames. A sketch showing a cross-section of this concept is shown below.



Typical cross section at portal frame locations

The fully enclosed structure will require some sort of ventilation system installed, this will most likely be in the form of fans installed along the roof. These fans can weigh a lot and the additional load may increase the member sizes significantly. This will be further explored in the SOR.

4.5 DESIGN LIFE

A key consideration is the Design Life of the provision to be investigated. Based on the likely reduction in air pollution over time with:

- more efficient engines;
- a move towards electric cars;
- legal sanctions if the environment is not improved; and
- specific Government intervention, including Clean Air Zones initiative

it was agreed that the Design Life should be 15 years at a maximum. However, it was noted that due to the maintenance cycle on some materials, this could be lowered to 10 years to allow for a situation where the replacement/repair cost could be avoided. Such exceptional circumstances were to be recorded so that a level playing field could be established between different potential solutions.

4.6 MATERIALS

The following materials are considered appropriate for consideration for both walls and roof cladding construction:

- Timber;
- Metal;
- Concrete;
- Perspex;
- Glass;
- Plastic fabrics such ethyl tetra fluro ethylene (ETFE); and
- Fabrics such as those used in large temporary or storage buildings.

The suitability of the above materials in relation to the Design Life criteria, a variety of other practical aspects of construction/maintenance/decommissioning, and the three options described above will be addressed in the SOR.

4.7 HEALTH & SAFETY AND OPERATIONAL CONSIDERATIONS

A number of general construction Health & Safety and operational issues have been considered by the WSP|PB team prior to the more detailed design of the proposed structures and these will be expanded upon in the SOR.

The view is expressed that avoiding the fully enclosed/tunnel option but maximising the mitigation ability of a partial enclosure may be the preferred solution from both health and safety and operational points of view.

4.8 CONCLUSIONS

The SOR is to look into the design of the three structures listed below:

- A vertical barrier with an inclined section over the carriageway;
- A cantilevered or portal structure which provide partial enclosure; and
- A structure which provided full enclosure of the carriageways.

It will determine the site specific, health and safety and constructability constraints and produce a suitable and efficient design using the concepts describe in this chapter as a starting point.

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5 STRUCTURES OPTIONS REPORT

5.1 INTRODUCTION

The Structures Option Report (SOR) is a stand-alone document and is included in its entirety as Appendix G in this report. The document outlines the high-level design of three different structures which could be possibly constructed to improve air quality near busy roads. These are a cantilevered barrier, a partially enclosed canopy and a fully enclosed canopy. The contents of the report, key findings and conclusion are provided below but it is recommended that the reader reads the appendix in full to fully understand the approach adopted and the conclusions reached.

5.2 CONTENTS OF THE SOR

As outlined in Appendix G, there is no formal layout for an SOR for this type of work. Accordingly, the structure below was agreed for the report with Highways England:

- Executive Summary
- Introduction
- Stakeholders and interfaces
- Geometric constraints
- Geotechnical constraints
- Environmental Constraints
- Existing structures
- Proposed structure materials
- Fire requirements
- Durability
- Architecture and finishes
- Drainage
- Construction, maintenance and operation considerations
- Design actions
- Deflection criteria
- Structure No. 1: a vertical barrier with an inclined section over the carriageway
- Structure No. 3: fully enclosed structure
- Structure No. 2: partially enclosed structure
- Cost estimate
- Qualitative assessment of air quality improvement
- Conclusions

with associated supporting tables, figures, drawings and appendices.

5.3 KEY POINTS FROM THE EARLY CHAPTERS OF THE SOR

There are a number of key points from the early chapters of the SOR as follows:

1. No specific location is identified for the proposed structures so assumptions have been made in relation to loading factors, ground conditions and environmental constraints. In all cases, practical values for loading and soil parameters have been used;
2. The concepts discussed in Chapter 4 above are the starting point for the design work carried out and changes to some of the proposals are made within the SOR with supportive reasoning provided;
3. There has been no stakeholder interfaces to date at Highways England's request;
4. The cross section included in the assessment assumes that of a D3M but with a 2.5 metre wide verge to accommodate foundations, communications, drainage, road restraint systems (RRS), etc;
5. The design assumes vertical clearance of 5.7 metres and a set back from the RRS to avoid the need for deigning for impact loading;
6. No account is taken at this time for the manner in which other structures within the highway – gantries, Advance Direction Signs, under or over bridges - can be accommodated until the specifics of a site are known;
7. Fire requirements are specifically looked at, especially in the case of the partial and fully enclosed options, with different potential approaches reviewed;
8. Durability of the structural elements can be achieved through the use of galvanised finishes, paint and intumescent coatings for the C5 environment;
9. None of the materials suggested for the wall or roof cladding can be easily dismissed but it was the view that ETFE and fabric were less suited to the purpose required;
10. A positive drainage system for rain running off the structures was recommended to maintain a degree of control over earthworks erosion and possible saturation of the sub-grade;
11. A wide variety of construction, maintenance and operation issues have been identified and recorded with potentially the most difficult ones to address being how to deal with snow ploughed up against the RRS and wall of the canopy structure and the need for a safe means of access to the outer surfaces of the fully enclosed structure; and
12. Maintenance loading i.e. that imparted by operatives walking on the roof surface was a necessary Action in loading calculation with deflection being the overriding criteria to address for user visual comfort.

5.4 STRUCTURAL DESIGNS AND COST ESTIMATES

With the above matters taken into account, a design for each of the structural options (Structures 1, 2 and 3 respectively) for the supporting steel frame was carried out. The basis of these designs was a timber wall and Perspex roof. These designs provided quantities for the subsequent construction cost estimates which were presented. These were calculated to be as follows:

Structure 1: £21.7 million per km, reducing to £10.9 million per km if only installed on one side

Structure 2: £31.1 million per km

Structure 3: £46.2 million per km

Different cladding options (for the wall and the roof) and the impact that they would have on the steel frame design were reviewed and costed also.

Maintenance costs were assessed for the three base designs and reported, ranging from £86,000 for Structure 1 to £175,000 for Structure 2 and £604,000 for Structure 3. These costs would apply to the 15 year Design Life and account for the scrap value of the steel structures and assumption that the foundations would be abandoned in-situ.

5.5 SUMMARY OF FINDINGS

A range of structures and developed designs have been explored. We feel these are efficient in terms of quantity of materials used, ease of construction, and low maintenance and running costs. The resulting designs are adaptable to a variety of situations and could be standardised and prefabricated for additional efficiencies.

We have explored different cladding materials such as ETFE, fabric, timber, glass and reinforced concrete, and concluded that due to price, weight, longevity, and on-going operations and maintenance cost, that the most appropriate combination of cladding material is timber or steel clad walls and translucent Perspex cladding on the roof on the structures.

The solutions we have proposed are feasible in terms of structural efficiency, constructability, and on-going maintenance cost.

The estimated construction cost of these structures, shown in Table 4 below, is comparable to the cost of other similar structures around the world and estimated in various studies.

STRUCTURE TYPE	ESTIMATED COST FROM AVAILABLE INFORMATION (FROM CHAPTER 3)	ESTIMATED COST OF WSP|PB CONCEPT DESIGNS
Cantilever Barrier	£5 million to £13 million (on one side of the road)	£21.7 million/km on both sides or the road or £10.9 million/km on one side of the road
Partially Enclosed Canopy	No structure studied is directly comparable to estimate a cost however it is expected that a significant saving can be made over the fully enclosed canopy.	£31.1 million/km
Fully Enclosed Canopy	£9 million to £77 million	£46.2 million/km

Table 4. Summary of estimated cost of structures

In relation to the range of materials available to the designer for use with the three selected structural forms, Table 5 overleaf provides cost information in regard to this matter.

STRUCTURE TYPE	ESTIMATED COST OF WSP|PB CONCEPT DESIGNS DEPENDING ON MATERIALS ASSESSED
Cantilever Barrier	£6.7 million to £19.2 million per kilometre (on one side of the road)
Partially Enclosed Canopy	£14.7 to £46.9 million per kilometre
Fully Enclosed Canopy	£23.2 to £71.6 million per kilometre

Table 5: Cost estimates from various sources for structure similar to Structure 1, 2 and 3

Other possibilities that could be explored to potentially offer significant cost savings for the partially and fully-enclosed canopies include:

- Installation of a support in the central reserve of a highway.
- Reducing the span of the canopy by building within the verge and designing for impact loading.

5.6 CONCLUSIONS

The following conclusions are taken from Chapter 21 of the SOR for ease of reference:

A feasible solution exists for the provision of Structure No. 1, 2 and 3, which can be advanced to mitigate the impacts of air dispersed pollutants from the SRN on adjacent receptors. Such provision will require the widening of verge provision to accommodate the structure at the rear of the verge area, allowing for drainage, Road Restraints Systems, drainage networks elements, communications cables and chambers, etc.

The structure solutions can be manufactured from a variety of materials, but it is recommended that Perspex or similar materials (in terms of weight, resistance to impact, see-through, etc) should be taken forward as the preferred option for the roofing material and that timber (in the form currently used for environmental barriers but with a greater level of air tightness) is utilised for the vertical wall components, linked to a steel frame structure.

The associated cost estimate for each structure has been determined as follows using this combination of materials i.e. timber for the vertical wall component; and Perspex for the roof section:

- *Structure No. 1 (a vertical barrier with an inclined roof section): £21.7 million / km*
- *Structure No. 2 (a partially enclosed canopy): £31.1 million/ km*
- *Structure No. 3 (a fully enclosed canopy): £46.2 million/ km*

It is noted that the costs for Structure 1 assumes that it is required on both sides of the carriageway. If not, the cost of provision on one side is thus recorded as being £10.9 million per km.

The costs above fall within the range of costs established for similar facilities by WSP|PB. It is stressed that the solution will be location specific but that on balance WSP|PB are minded that the combination of timber wall and Perspex roof provide the starting point for discussion.

In areas where visual impact is not an issue, a metal wall and metal roof option would provide the best economic solution.

If the issues associated with the use of fabric structures can be addressed, it may be worth investigating the option more thoroughly. Fabric covered structures offer the potential for a significantly cheaper alternative in certain circumstances if their shortcomings of the material can be addressed or accommodated.

It is confirmed that the SOR contained in Appendix G has been technically approved by Mr Jim Gallagher, the Highways England Structures Advisor for this commission.

6 RISK REVIEW

In Table 6 below, risks have been identified which could impact on the price and effectiveness of the structures proposed in the SOR with the suggested mitigation to be undertaken at further stages.

RISK	MITIGATION
In the absence of software to accurately predict the manner in which air flows and pollution dispersal will take place around (Structure No. 1 and 2), significant expenditure without proven results may be difficult in the Business Case process.	The mitigation is to engage more with the software houses and assess what they are working on in terms of upgrades and the next evolution of CFD.
The impact of specific geotechnical conditions at the chosen site on the overall foundation design is not clear at this time.	The mitigation is to adopt reasonable parameters based on experience. When specific locations are identified, interrogation of the Highways England geotechnical data base and a targeted ground investigation will be required to get an idea of the impact to the foundations.
The impact of specific environmental conditions at the chosen site on the overall design is not clear at this time.	There is no immediate mitigation for this situation at this time, as each site will have unique environmental characteristics. Maintaining a flexible approach to the design process and selection of the optimum solution for a given location is key at this time.
At sites with little distance between the edge of the verge and the highway boundary, additional land may need to be acquired form adjacent properties.	To mitigate this, this issue needs to be considered when looking at the appropriateness of these solutions at particular sites. If a decision is made to pursue one of these solutions even though land acquisition may be required, effort by the detailed design teams will need to be made to reduce the land required as much as reasonably possible.
The views of national stakeholders are not known at this time.	This can be counteracted by a formal workshop at an appropriate time through Highways England and the contacts established to date.
More detailed discussions in relation to fire precautions may result in additional provision with associated costs being required.	Include specialists within Highways England in the review of this document so that their position is known as early as possible. For future design stages the criteria will need to be defined by Highways England.
The specific manner in which existing structures would be accommodated within these structures e.g. new gantries, has not been considered in the reporting prepared to date.	The specific situations which need to be considered will need to be set out by Highways England for future design development of the options. Any necessary modification to the proposed structures can then be investigated.
The level of detail available to the designers at this time will be reflected in the accuracy and quantum of pricing risk included in the reported costs. As more detail comes to light in subsequent stages of development, the anticipated cost may change. There is a risk that the reported costs do not reflect the cost of the final design.	A balance between the accuracy of the quantities taken off by the quantity surveyors and the pricing accuracy will be through a process of pricing of the structure through its phases via the reduction in the Optimism Bias as per governmental guidance.

RISK	MITIGATION
Whilst every effort has been made to consider CDM 2015 design, construction, operational and demolition risks in the working up of the designs to date, it may be the case that unexpected Health and Safety risks are identified as part of the design process which could result in delays to the design and installation stages.	During the next phase of design development, hold a workshop with constructors and designers to identify all potential health and safety issues.

Table 6: Risks and Mitigations

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 CONCLUSIONS

From the work undertaken in this study, the following conclusions can be made:

- The solutions we have proposed are feasible in terms of structural efficiency, constructability, and on-going maintenance cost. They are based on commonly available materials and existing construction methodologies.
- Estimated costs of these structures are in line with the range established from various sources (papers and case studies) that have been investigated during this commission.
- Refinements of the costs and design of these structures is thought to be possible under a number of avenues and should be explored if this project progresses to a further stage.

7.2 RECOMMENDATION

The following recommendations are made to Highways England for moving this work forward:

- More defined criteria is determined by Highways England for future investigation of the structures – including specific road cross sections to be accommodated, design life, specific site locations – so conditions in relation to the ground, atmospheric conditions, traffic flows, and so on can be taken accurately into the design process.
- After the needs of Highways England, the UK Local authorities and DfT are established in relation to air quality modelling it is recommended that contact is established with software houses who design CFD software with the goal of the advancement of the modelling software to suit these needs; i.e. software that is capable of modelling cantilever barrier structures and partially enclosed canopy structures. This will help establish the mitigation benefits in a quantifiable manner for these structures.
- The cost estimates are reviewed by Highways England's commercial team. It is also recommended that contact is made with UK manufactures of portal frames and the preferred wall and roof cladding materials so that any cost savings related to fabrication, transport and on-site activities can be maximised.

It is noted that, at Highway England's request, the latter point above is currently being actioned by WSP|PB and will be reported upon as an addendum to this report.

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Appendix A

TASK SPECIFICATION CANOPIES 551091 FINAL

Specification for Research into the development of a cost–effective Canopy (or tunnel type structure) including air treatment system and /or overhanging structure on a Motorway to improve air quality.

1. Introduction

Highways England is looking to set up a contract for the provision of services to undertake research into the development of cost effective Canopy and / or overhanging free standing structure on the strategic road network (SRN) to improve air quality.

Air quality is a significant risk to the roads program for Highways England, poor air quality can also have an adverse impact on health for those residing in areas of poor air quality. Given this risk to the business there is a need to identify and develop cost-effective mitigation measures that may be adopted to both improve air quality alongside the SRN and support schemes delivery.

This project is a feasibility study to determine whether a canopy or overhanging type structure could be built over a motorway and whether the structure could be built cost effectively to make it an economically viable mitigation option.

2. Background

The open access arrangements for the motorway network in England, means that Highways England has very limited controls over the vehicles that travel on our network. Consequently it is difficult to control those emissions that effect residents living close to our road network. We are identifying measures that could be used to help mitigate the impacts of the emissions that are produced by the vehicles on our road network. This package of works supports this activity.

Highways England is currently trialling a 4m (with option to extend to 6m) high barrier located on the M62. In theory the barrier, increases the distance pollution travels from the road source to the receptor, and so lowers concentrations at receptors.

Taking this measure further and creating a structure that covers the entire road to block pollutants from getting to receptors would eliminate the roadside element of concentrations at receptors. This would improve air quality at receptors with the highest concentrations to below the Limit Values as set out in the European Directive on Ambient Air Quality.

Previous work undertaken by the Dutch Roads Authority indicates that there are considerable costs attributed to the design and build of enclosing a section of motorway in a canopy. Research undertaken by the Dutch Innovation Programme indicated that the cost ranged between €15m and €70m per kilometre (£10.5m to £50m). These costs would mean that it is highly unlikely that this measure could be used on an actual scheme once the costs have been factored into the benefit cost ratio (BCR), it would likely mean that the scheme would not be financially viable.

It is clear that as a mitigation measure it would work, therefore the purpose of this task is not to prove it's an effective air quality mitigation measure, but to determine whether a structure could be constructed over the motorway with significantly reduced costs from those identified in the current research.

Alternatively, noise barriers in Europe and elsewhere include considerable overhangs covering up to 2 to 3 lanes of traffic. Whilst not designed to mitigate the effects of air quality these barriers may also offer possible improvements in air quality and should also be investigated as part of this project (in relation to costs and possible air quality mitigation benefits).

This project should build on previous research elsewhere, seeking to find new and innovative approaches to deliver similar structures in a more cost effective way.

3. Requirements

3.1. Objectives

The following objectives have been identified for this study;

1. Investigate how a Canopy (or tunnel type structure) could be built economically and could be constructed over both carriageways of a motorway.
2. Produce a high level design of the structure providing high level costs for its construction, maintenance and decommissioning.

3.2. Work Required

- Review work undertaken by other countries relating to the enclosure of a road;
- Determine the type of structures that could be constructed which would create a barrier over the motorway and therefore eliminate the roadside component of concentrations of pollutants;
- Consider the effectiveness of barriers that provide partial coverage based on current evidence;
- It is envisaged that a number of designs could be identified highlighting strengths and weaknesses of each design;
- Provide cost estimates for the construction of the structure per kilometre, given that emissions have the potential to significantly reduce as a result of newer vehicles the structure could be temporary, this should be considered as part of the costs;
- Consider lifecycle costs including maintenance and decommission of the proposed structures;
- Consider the consequences of any structure on others e.g. visual impact on road users and local residents, health and safety, maintenance and site access;
- Produce a Structures Options Report listing the main design proposals. Refer to BD 2/12 taking account of the requirements of Clauses 2.12 & 2.13.

- Produce outline designs of the main structures options (at this stage we are not expecting a detailed design) that would meet the objectives of the canopy / overhanging barrier, i.e. impermeably and meets the construction requirements for a structure built on the Highways England's network;
- Work with Highways England structural leads in NetServ to ensure that the structure would meet appropriate standards;
- Determine the level of complexity of constructing such a structure to determine its ability to be used as a mitigation measure as part of a scheme. Given that receptors (i.e. houses) that we will be trying to improve the air quality at will be located very close to the structure (e.g. on the M60 houses are located within 5m of the hard shoulder) this needs to be considered as part of the design. It would be no use for example if the structure needed to be constructed with clearances of 50m each side of the motorway as the receptors with the highest concentrations and hence those requiring the mitigation measure are located in this area;
- Consider how a canopy would be ventilated and lit, given that if viable these structures could be many kilometres long;
- Consider potential risks associated with each proposed design;
- Review the potential for wind funnelling/shielding, drainage, snow, accumulation, etc. and possible effects on the structure and traffic;
- Determine whether the structure could be constructed at a significantly reduced cost to the figures quoted in the Dutch research;
- Identify any land constraints required to support such a structure;
- Produce a report detailing the findings of the assessment, including recommendations for any approach and costings for all proposed. options.

4. Responsibilities

The work will be carried out by structural specialists within your organisation with a high level of expertise and demonstrable experience of working on highway projects including for Highways England (Highways Agency) schemes. It is not envisaged there will be a need for significant input from an air quality specialists given the purpose of the assessment is to provide a canopy design and to determine the cost of constructing the structure.

5. Skills/Experience

5.1. Essential Skills

- Expert knowledge and recent experience of designing structures in support of highways schemes;
- Experience of quality assurance and control procedures
- Good written presentation skills. Able to present complex information in a succinct and accessible manner
- Works on own initiative

5.2. Desirable Skills

- Experience of designing Tunnels, light weight structures, barriers.

6. Deliverables

The following deliverables will be required as part of this commission;

1. Initial inception meeting in Manchester;
2. Literature Review;
3. High level design of a Canopy / overhanging barrier, including potential ventilation requirements;
4. Estimated costs for the build of the preferred design;
5. Report presenting the findings;
6. Monthly review meetings (by telephone)

It is envisaged that there will be a number of points in the program where we will review the findings prior to progression to the next stage, these should be considered and identified in the tender.

7. Location

Suppliers can be based anywhere in the UK, although there is reasonable expected for travel for presentation in Highways England's office in Manchester.

8. Timescales

- The proposed start date of the contract 14 August 2015.
- Duration (9 Months).

9. Payment & Budgetary Control

The basis for payment shall be time charges and expenses in accordance with CDF Framework Information for Lot 1 – Consultancy Service, and will be based on a PSC contract using option E – Cost Reimbursable and the reimbursements of costs for approved sub-consultants.

Robust forecasts must be submitted at the start of the Task and at monthly intervals. There must be a variance of no greater than + or – 10% between in month forecasts and expenditure. If a variance above 10% occurs an explanation as to why this has occurred and the effect on the rest of the project must be provided in writing to the Project Manager within 5 working days of the Consultant or Project Manager becoming aware of the variance. An accurate statement of the value of work undertaken and the resource consumed in each month must be submitted to the Project Manager, in the form of a CMR and draft invoice, at least 5 working days before the end of each month.

The total cost of the project must not exceed the total Task value, i.e. the value of the Blanket Purchase Agreement (BPA), without the prior written authorisation. No work outside the scope of this Brief must be carried out without the prior written authorisation. Each request for additional work must be supported by an estimate of the implications on the Task and Deliverable, cost and programme.

10. Additional Information

The performance of the Consultant will be monitored on a not less than quarterly basis, at financial year quarters and at completion of the Task using Collaborative Performance Framework toolkit.

11. Contact Information

Role	Location	Phone
Project Sponsor	Andrew Bean	0161 930 5526
Project Manager	Stephen Pyatt Jim Gallagher	0161 930 4474 0161 930 5527
Procurement Officer	Rita Karra	0121 678 8233

Appendix B

POLLUTANTS

APPENDIX B:

EXPLANATION REGARDING MOST SIGNIFICANT POLLUTANTS

NO_x includes nitrogen dioxide (NO_2) and nitrogen oxide (NO). NO is generally considered to be a relatively innocuous compound in ambient air, however once released into the atmosphere it is converted to NO_2 via a reaction with oxygen in the ambient air. NO_2 is associated with adverse effects on human health, and the air quality legislation includes long and short term standards for NO_2 for the protection of human health. High concentrations of NO_x can also have an adverse effect on vegetation, including leaf damage and reduced growth, and the air quality legislation therefore includes a standard for NO_x for the protection of ecology.

Particulate matter is made up of a wide range of materials from both natural and human produced sources. The larger particles fall out of suspension relatively quickly and are of concern more for nuisance dust issues rather than human health issues. The finer particles, generally those smaller than 10µm in diameter (known as PM_{10}) are small enough to be drawn into the lungs during breathing, potentially causing adverse health effects associated with respiratory and cardiovascular illness. As a result the air quality legislation includes long and short term standards for PM_{10}. Recent evidence has suggested that the finer fraction of particles, less than 2.5µg/m^3 in diameter (known as $PM_{2.5}$ and typically making up around two thirds of PM_{10} emissions and concentrations), gives a stronger association with adverse health effects than PM_{10}. Therefore, more recently the air quality legislation has been revised to include a standard for $PM_{2.5}$ for the protection of human health.

Appendix C

EUROPEAN LEGISLATION

APPENDIX C:

EUROPEAN LEGISLATION RELATING TO AIR QUALITY

AIR QUALITY DIRECTIVE 2008/50/EC

The Air Quality Directive 2008/50/EC[1] came into force on 11 June 2008. This directive merged three existing Directives and one Council Decision[2] into a single Directive on air quality. It sets air quality limit values, target values, and critical levels for a number of air pollutants established by the European Parliament and Council for the protection of human health, vegetation and ecosystems. These are sulphur dioxide (SO_2), nitrogen dioxide (NO_2), oxides of nitrogen (NO_X) particulate matter (PM_{10} and $PM_{2.5}$), lead (Pb), benzene (C_6H_6), carbon monoxide (CO) and ozone (O_3).

For the pollutants considered in this study, the limit values for the protection of human health as outlined in Annex XI of this Directive are presented in Table 1 below. The directive states that Member States shall ensure that the relevant pollutant concentrations in ambient air do not exceed these levels.

Table 1. Limit values for the protection of human health

POLLUTANT	AVERAGING PERIOD	LIMIT VALUE	TARGET DATE
Nitrogen dioxide	One Hour	200 µg/m^3, not to be exceeded more than 18 times a calendar year	1st January 2010
	Calendar Year	40 µg/m^3	1st January 2010
Benzene	Calendar Year	5 µg/m^3	1st January 2010
Carbon monoxide	Maximum daily eight hour mean	10 mg/m^3	1st January 2005
PM_{10}	One Day	50 µg/m^3, not to be exceeded more than 35 times a calendar year	1st January 2005
	Calendar Year	40 µg/m^3	1st January 2005

For the relevant pollutant (NO_x), the critical level for the protection of vegetation outlined in Annex XIII of this Directive is presented in Table 2 below. The Directive states that Member States shall ensure compliance with this critical level.

Table 2. Critical levels of the protection of vegetation

POLLUTANT	AVERAGING PERIOD	CRITICAL LEVEL
Oxides of nitrogen	Calendar Year	30 µg/m^3

[1] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe;

[2] Framework Directive 96/62EC, 1-3 daughter Directives 1999/30/EC, 2000/69/EC, 2002/3/EC and Decision on Exchange of Information 97/101/EC

For $PM_{2.5}$, there is a target value and a limit value for the protection of human health. These are detailed in Section D and E of Annex XIV of the Directive and are reproduced in **Table 3** below. The Directive states that Member States shall take all necessary measures not entailing disproportionate costs to ensure that concentrations of $PM_{2.5}$ in ambient air do not exceed the target value. It also states that Member States shall ensure that concentrations of $PM_{2.5}$ in ambient air do not exceed the limit value throughout their zones and agglomerations by the specified date.

Table 3. Target and limit values for $PM_{2.5}$ for the protection of human health

TYPE	AVERAGING PERIOD	VALUE	DATE TO BE ACHIEVED
Target Value	Calendar Year	25 µg/m^3	1st January 2010
Limit Value (Stage 1)	Calendar Year	25 µg/m^3	1st January 2015
Limit Value (Stage 2)	Calendar Year	20 µg/m^3	1st January 2020

In addition, the Directive also states that Member States shall take all necessary measures not entailing disproportionate costs to reduce exposure to $PM_{2.5}$ with a view to attaining the national exposure reduction target outlined in Section B of Annex XIV of the Directive. The magnitude of the required reduction depends on the national average concentration over a three year period between 2009 and 2011 measured at urban background locations. The table below indicates how the reduction target is calculated.

Table 4. Exposure reduction target for $PM_{2.5}$ for the protection of human health

INITIAL CONCENTRATION IN µG/M3	REDUCTION TARGET (%)	REDUCTION TARGET DATE
< 8.5 = 8.5	0%	2020
>8.5 - <13	10%	
13 - <18	15%	
18 - <22	20%	
≥ 22	All appropriate measures to achieve 18 µg/m^3	

For the UK, from the 47 $PM_{2.5}$ stations used in a study by DEFRA in 2011, the average $PM_{2.5}$ concentration for 2009-2011 was between 13-14 µg/m^3. Therefore the UK is required to comply with a 15% reduction target for 2020.

THE AIR QUALITY STANDARDS REGULATIONS 2010

The Air Quality Standards Regulations 2010[3] transpose EU Directive 2008/50/EC in to UK legislation.

[3] The Air Quality Standards Regulations 2010 - Statutory Instrument 2010 No. 1001

Appendix D

UK LEGISLATION

APPENDIX D:

UK LEGISLATION IN RELATION TO AIR QUALITY

AIR QUALITY STRATEGY FOR ENGLAND, SCOTLAND, WALES AND NORTHERN IRELAND

The Government's policy on air quality within the UK is set out in the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (AQS) published in July 2007[1]. The AQS provides a framework for reducing air pollution in the UK with the aim of meeting the requirements of European Union legislation and international commitments.

The AQS also sets standards and objectives for nine key air pollutants to protect health, vegetation and ecosystems. These are benzene (C_6H_6), 1,3 butadiene (C_4H_6), carbon monoxide (CO), lead (Pb), nitrogen dioxide (NO_2), particulate matter (PM_{10} and $PM_{2.5}$), sulphur dioxide (SO_2), ozone (O_3), and polycyclic aromatic hydrocarbons (PAHs). The objectives for the pollutants relevant to this study included in the AQS are provided in the Tables 1 and 2.

For some pollutants, (e.g. NO_2), there is both a long-term standard (annual mean) and a short-term standard. In the case of NO_2, the short-term standard is for a one-hour averaging period, whereas for PM_{10} it is for a 24-hour averaging period. These periods reflect the varying effects on health of differing exposures to pollutants, for example temporary exposure on the pavement adjacent to a busy road, compared with the exposure of residential properties adjacent to a road.

The AQS contains a framework for considering the effects of a finer group of particles known as '$PM_{2.5}$' as there is increasing evidence that this size class of particles can be more closely associated with observed adverse health effects than PM_{10}. For $PM_{2.5}$ the objectives are a limit value and an 'exposure reduction' target. Although a target for $PM_{2.5}$ is included in the AQS, these objectives have not yet been incorporated into the Regulations.

Table 1. AQS objectives for the protection of human health

POLLUTANT	APPLIES	OBJECTIVE	AVERAGING PERIOD	TARGET DATE
Particles (PM_{10})	UK	50 µg/m^3, not to be exceeded more than 35 times a year	24 hour mean	31st December 2004
	UK	40 µg/m^3	Annual mean	31st December 2004
	Scotland	50 µg/m^3, not to be exceeded more than 7 times a year	24 hour mean	31st December 2010
	Scotland	18 µg/m^3	Annual mean	31st December 2010
Particles ($PM_{2.5}$) Exposure Reduction	UK (except Scotland)	25 µg/m^3	Annual mean	2020
	Scotland	12 µg/m^3		2020
	UK urban areas	Target of 15% reductions in concentrations at urban background		Between 2010 and 2020

[1] Department for Environment, Food and Rural Affairs (DEFRA) and the Devolved Administrations (2007). The Air Quality Strategy for England, Scotland, Wales and Northern Ireland (Volumes 1 and 2)

POLLUTANT	APPLIES	OBJECTIVE	AVERAGING PERIOD	TARGET DATE
Nitrogen dioxide	UK	200 µg/m^3, not to be exceeded more than 18 times a year	1 hour mean	31st December 2005
	UK	40 µg/m^3	Annual mean	31st December 2005
Benzene	UK	16.25 µg/m^3	Running annual mean	31st December 2003
	England and Wales	5 µg/m^3	Annual average	31st December 2010
	Scoland, Northern Ireland	3.25 µg/m^3	Running annual mean	31st December 2010
1,3- butadiene	UK	2.25 µg/m^3	Running annual mean	31st December 2003
Carbon monoxide	UK	10 mg/m^3	Maximum daily running 8 hour mean in Scotland as running 8 hour mean	31st December 2003

Table 2. AQS objectives for the protection of vegetation and ecosystems

POLLUTANT	APPLIES	OBJECTIVE	AVERAGING PERIOD	TARGET DATE
Nitrogen Oxides	UK	30 µg/m^3	Annual mean	31st December 2000

THE AIR QUALITY REGULATIONS

In England, most of the objectives in the AQS (which was originally published in 1997, with subsequent revisions in 2000 and 2007) have been made statutory in England with the Air Quality (England) Regulations 2000[2] and the Air Quality (England) (Amendment) Regulations 2002[3].

The Regulations require that where figures will likely exceed the Air Quality Objectives, they must be assessed in relation to:

"…the quality of the air at locations which are situated outside of buildings or other natural or man-made structures, above or below ground, and where members of the public are regularly present…"

Similarly most of the objectives in the AQS have been made statutory in Wales with the Air Quality (Wales) Regulations 2000[4] and the Air Quality (Wales) (Amendment) Regulations 2002[5] and in Scotland with the Air Quality (Scotland) Regulations 2000[6] and the Air Quality (Scotland) (Amendment) Regulations 2002[7].

The Air Quality Objectives apply only where members of the public are likely to be regularly present for the averaging time of the objectives (that is, where people will be exposed to pollutants). The annual mean objectives apply to all external locations where members of the public might be regularly exposed; these include building façades of residential properties, schools, hospitals, care homes etc. The 24-hour mean objectives apply to all locations where the annual mean objective would apply, together with hotels and gardens of residential properties. The one-hour mean objectives also apply at these locations as well as at any

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[2] The Air Quality (England) Regulations 2000 - Statutory Instrument 2000 No.928
[3] The Air Quality (England) (Amendment) Regulations 2002- Statutory Instrument 2002 No.3043
[4] The Air Quality (Wales) Regulations 2000 – Statutory Instrument 2000 No. 1940 (W)
[5] The Air Quality (Wales) (Amendment) Regulations 2002 – Welsh Statutory Instrument 2002 No 3182 (W 298)
[6] The Air Quality (Scotland) Regulations 2000 – Scottish Statutory Instrument 2000 No. 97
[7] The Air Quality (Scotland) (Amendment) Regulations 2002 – Scottish Statutory Instrument 2002 No 297

outdoor location where a member of the public might reasonably be expected to stay for one hour or more, such as shopping streets, parks and sports grounds, as well as bus stations and railway stations that are not fully enclosed.

These periods reflect the varying effects on health of differing exposures to pollutants, for example temporary exposure on the pavement adjacent to a busy road, compared with the exposure of residential properties adjacent to a road and do not specifically apply to drivers on those roads.

Appendix E

AIR QUALITY IN TUNNELS

APPENDIX E:

AIR QUALITY IN TUNNELS

This appendix is to provide information in regard to the research carried out by WSP|PB for air quality in a tunnel environment which is not well covered in other documentation.

It is noted that the short term ambient air quality standards are applicable, as included in Table 1 of Appendix D of this report.

In addition to these, there are short-term Environmental Assessment Levels (EAL) outlined in Annex F of the Environment Agency H1 guidance note. The EAL applicable to emissions from road traffic are as follows:

SUBSTANCE	SHORT TERM EAL (µG/M^3)
Carbon monoxide (CO)	30,000

For the purposes of designing tunnel ventilation systems, design and threshold pollution values are provided in the PIARC publication Technical Committee C4 Road Tunnels Operation (2012). Road Tunnels: Vehicle Emissions and Air Demand for Ventilation and are presented in the table below:

TRAFFIC SITUATION	CO (PPM)
Free flowing peak traffic 50 – 100km/h	70
Daily congested traffic, stopped on all lanes	70
Exceptional congested traffic, stopped on all lanes	100
Planned maintenance work in a tunnel under traffic	20
Threshold values for closing the tunnel	200

The PIARC publication also provides threshold values for NO_2 for the protection of the environment close to the tunnel portals or at ventilation outlets in order to protect tunnel users.

In an enclosed environment such as a tunnel, the concentration of NO is considered to be a more significant pollutant than in the ambient air. NO converts to NO_2 by reacting with oxygen (O_2) or ozone (O_3). In a tunnel environment, the speed of conversion of NO to NO_2 is much slower than in ambient air.

The British Tunnelling Society (April 2008) *Occupational Exposure to Nitrogen Monoxide in a Tunnel Environment: Best Practice Guide* notes that Health and Safety Executive (HSE) has withdrawn the Occupational Environmental Standard for nitrogen monoxide (or nitrogen oxide, NO) from EH40 and, therefore, that the Control of Substances Hazardous to Health (COSHH) Regulations should be applied instead. The COSHH Regulations require that where exposure to a harmful substance cannot be avoided that the exposure must be adequately controlled using the prescribed eight principles of good practice, including minimisation of emissions, release and spread, choose effective control options, personal protective equipment, providing information and training, etc.

If the substance causes cancer, heritable genetic damage or asthma, the exposure level must be reduced to As Low As Reasonably Practicable (ALARP). NO may cause emphysema with symptoms that are similar to asthma; therefore exposure to it requires control to the ALARP standard. The key recommendations are outlined in the guide including

- target level of NO should be no greater than 3ppm (8-hour Time Weighted Average (TWA));
- NO levels should not exceed 5ppm (8-hour TWA);
- Peak NO levels should not exceed 15ppm (15-minute mean); and
- NO levels should be monitored and recorded and health surveillance should be considered.

Appendix F

OTHER DUTCH STUDY FINDINGS

APPENDIX F:

DUTCH STUDY FINDINGS

ROADSIDE VEGETATION

The Dutch study looked into the effect of vegetation on air quality and found that it only had a slightly positive, but statistically not significant effect. The Scientific Broad review of the study noted many improvements that could have been made in the study but also noted the difficulty in evaluating the improvements and the many variables that could affect results.

However, studies in the US (Bowker et al (2007), Baldauf et al (2008)) as referred to elsewhere in this report suggest that the use of mature trees behind barriers improve air mixing and reduce pollutant levels relative to the barrier alone.

Currently there is not strong evidence that vegetation near roads has any significant effect on the quality of air, unless in combination with barriers. The other issue associated with the provision of a “green” barrier is the time required for its establishment. With a typical design life for the air quality barrier being some 10 to 15 years, the vegetation will not be fully established by the anticipated time the problem of pollutants is easing. Additionally green solutions require plan area in which planting is to be provided which is not necessarily available at current key air quality problem locations – largely due to the proximity of the receptor to the carriageway preventing easy provision of screening. It is noted that the provision of vegetation has additional environmental advantages including probable reduction in driver stress, helping to establish new ecological habitats, being more sympathetic for the receptor than a physical structure.

Accordingly, the use of vegetation near roads will not be further looked into as an option for improving the air quality near roads despite the additional advantages outlined above.

KEY FINDINGS

The use of vegetation alone to improve air quality has not been reliably demonstrated in the literature. However mature trees, if present or planted and allowed to grow for a significant time, may have a beneficial effect when placed behind barriers.

ROAD SURFACE CLEANING

Cleaning the road surface with a chemical solution can be an effective way to reduce the number of particles in the air. However, the Dutch study found that the effectiveness can be reliant on the type of road surfacing and solution used. It also noted the capacity for road cleaning to improve the air quality is limited as the particles in the air from the road surface typically only make a small percentage of the total particles in the air.

The Dutch study was able to conclude that the spraying of hygroscopic agents such as Calcium Chloride ($CaCl_2$), was found to suppress road traffic contribution to overall PM_{10} levels by about 10% but no agreement and conclusion could be made of optimal road surfacing materials to maximise its benefits.

While it seems that this option can reduce the amount of particles in the air, the reduction is only small and it does not affect the NO_x and NO_2 level in the air. Employing this option also requires daily cleaning of the road with the associated implication on delay and disruption for road users and safety of vehicle operatives especially on multi-lane carriageways. Whilst it is accepted that rainfall will be less likely on hot still days i.e. those which would be worse for air quality conditions, the availability of the product on the road surface after precipitation events until the next application would be very much reduced.

While the process could help reduce PM_{10} level for a period of time, it is not considered to be a long term option and thus will not be explored further during this study which is to concentrate on structural solutions.

KEY FINDINGS

The use of road surface cleaning is not to be considered further in this commission.

CATALYTIC COATINGS

By coating barriers or other roadside structures in a titanium dioxide (TiO_2), the TiO_2 will act as a photo-catalyst with ultra-violet light to break down NO_2 and NO in the air, converting them into innocuous nitrate (N_3). This hypothesis was tested as part of the Dutch study with two series of trials at two separate locations. The first measured four different coatings on panels attached to existing noise barriers and the second tested a porous noise barrier that had been optimised to improve the air quality mitigation with a coating. Both trials showed a poor rate of reaction and conversion of NO_2 and NO in the nitrate. It was speculated that this may have been because the airflow characteristics did not allow sufficient time for the reaction to occur, or due to unfavourable meteorological conditions in the Netherlands (wind direction and light intensity), the high relative humidity and low temperatures.

Little evidence has been found to show that catalytic coatings on vertical barriers in a free air environment would be effective for improving air quality. The climate in the UK is similar to that in the Netherlands and so it is likely that a similar result may be expected in the UK.

Further investigations not included in the Dutch Study but recorded here

Various products are available from research WSP|PB has undertaken. These include KnoxOut, a product marketed by Boysen Paints, which has documented evidence from a number of case studies available at http://www.knoxoutpaints.com/home.do relating to projects in the Philippines, Japan and France. Generally these are in more enclosed spaces e.g. tunnels and car parks which supports the suggestion that low air speeds are important to maximise contact time.

It appears possible in principle that the use of coatings within canopies may be more effective than on vertical barriers, since the air is in contact with the coated surface for a greater time. More research is needed to verify this hypothesis.

An approach has been made to the distributors of the product by e-mail but to date no response in regard to cost of supply for a nominal 500 litres to a UK Midlands location has been received.

A variation on the use of paints is the incorporation of TiO_2 into paving slabs and surfacings used for roads, footways, boundary walls. Details of recent studies are documented in:

http://phys.org/journals/journal-of-hazardous-materials/ which reports on a Eindhoven University of Technology study which purports to provide a 19% reduction in nitrogen oxide levels above paving slabs containing the additive and a maximum reduction of some 45% in perfect conditions;

Information published by Fraunhofer-Gesellschaft , a German based research group at Fraunhofer Institute for Molecular Biology and Applied Ecology IME (see http://phys.org/news/2010-08-paving-slabs-air.html) advised of typical reductions of 20 to 30% in recorded nitrogen oxide due to degradation in city canyon environment through the use of a proprietary cement design mix in so called Air Clean paving slabs.

Contact has been established with IME and F.C. Nüdling Betonelemente on the matter. They have referred WSP|PB to the UK distributor of their product, Tobermore. The latter has kindly replied to our approach with the text below extracted from their response "*Our initial thoughts on the costing of the products are that the price of the products will double. Therefore a standard* *block paving product which costs £10-15 per sqm will cost £20-£30 per sqm when produced in an Air Clean format*"; and

An MSc thesis by M C Burton at the University of Washington in regard to "Pervious concrete with Titanium Dioxide as a photo-catalyst compound for a greener urban road environment" available at http://www.dissertations.wsu.edu/Thesis/Fall2011/m_burton_112111.pdf indicates strong benefits of using a rough textured concrete surface coated with the chemical to reduce air pollutant concentrations.

Closer to home, Noxer blocks, pioneered in traffic-choked Tokyo, have been trialled in Kendal, Cumbria as part of the streetscape improvement works using materials supplied by Marshalls in mid-2012. No data is readily available as to their success, as it was accepted that "*it would be difficult to measure the effect of the paving*" and they were "*not the (only) answer to air problems in the town*". Also, Camden Council carried out a two-year trial of titanium dioxide-containing paint by a firm called Cristal (KnoxOUT) which showed significant reductions in pollutants – up to 65% – a short distance from the wall on which the paint was applied.

KEY FINDINGS

There is supportable evidence that the use of TiO_2 is beneficial in relation to the conversion of NO_x to N_3. The key issues appear to be the relative roughness of the surface and the duration for which the polluted air is in contact with the treated surface. On the basis that the cost of providing the catalyst is relatively low, its inclusion as a covering on a canopy or tunnel type structure should be considered.

Location in the world	Worldwide
Primary purpose for the work	Air quality, investigation of the use of TiO_2 in improving air quality
Air quality benefits assessed?	Yes solely
Materials used/suggested?	Paint or TiO_2 as an additive in concrete, paviours or paving slabs
Cost	Information from Cumbria Council indicates that specialised paving is available at no additional cost. This is possibly a lost leader on the part of the supplier to get market share as information from the Clear Air supplier is significantly different. TiO2 is a commonly available chemical, produced worldwide.
Buildability issues?	None identified
Health and safety issues associated with the proposed provision or its maintenance	None identified although research by Indiana University environmental scientists shows that air-pollution-removal technology used in "self-cleaning" paints and building surfaces may actually cause more problems than they solve, http://www.environment.indiana.edu/news/_2013/self-cleaning_pollution-control.php

DTM AND AIR QUALITY FORECASTS

Emissions are lower when traffic is smooth-flowing and not congested. Dynamic Traffic Management (DTM) can be used in some situations to reduce air pollution at peak traffic times or when air pollution is predicted to exceed recommended levels (due to weather or other external factors). It has been found that DTM can be used to reduce the short term concentration of PM10 particles but does have a similar effect on long term concentrations.

The Dutch study initially modelled the effect on a number of roads and found that the effectiveness depended on the local traffic situations. Factors include the volume of traffic and the amount of congestion. Implementing DTM on high speed roads only has a limited effect as the congestion is typical low. Field tests showed that in certain traffic situations DTM can have a positive effect on the air quality however the study encountered difficulties in assessing the magnitude of the impact due to the complex dynamic nature of the traffic conditions and the weather. The Dutch study also found it very difficult to predict when PM10 levels were going to be exceeded making it difficult to reliably and proactively implement DTM to control PM_{10} levels.

DTM could in principle be an effective solution to reduce short term PM_{10} values. However the evidence suggests that long term PM_{10} values, $PM_{2.5}$, NO_2 and NO might not be significantly affected by DTM.

KEY FINDINGS

The use of speed control for congestion reduction is commonly practiced in the UK at this time on those sections of the motorway which operate as Smart Motorways. It is unclear if Highways England has data in relation to air quality changes specifically in relation to DTM or its UK equivalent. Whilst it is a tool available to Highways England, the use of DTM or equivalent is not considered further here as it does not address the brief in relation to canopy or tunnel type structures but rather would be part of a greater traffic management/capacity approach to other problems on the network.

Appendix G

STRUCTURES OPTIONS REPORTS

CANOPY RESEARCH AND DEVELOPMENT STRUCTURES OPTIONS REPORT

PUBLIC

MAY 2016

CANOPY RESEARCH AND DEVELOPMENT
STRUCTURES OPTIONS REPORT

HIGHWAYS ENGLAND

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TABLE OF CONTENTS

FIGURES

TABLES

APPENDICES

1 EXECUTIVE SUMMARY

From work undertaken previously on the Canopy Research and Development commission, this Structures Options Report (SOR) investigates the structural solutions available for an environmental barrier on the Strategic Road Network (SRN) which aims to improve the air quality at adjacent receptors.

The report aims to provide structural solutions with sufficient detail to allow cost estimates for each structure to be determined and an estimate made on their potential air quality improvements at receptors. Based on the combination of cost, productivity, Design Life, operational safety and maintenance, the following structural forms for the environmental barriers are considered:

- Structure No. 1: A vertical barrier with an inclined section over the carriageway
- Structure No. 2: A partially enclosed canopy
- Structure No. 3: A fully enclosed canopy.

The report describes the proposed designs of these structures and their estimated costs based on the materials set out below. A summary of this is below:

<u>Structure 1: Cantilever canopy</u>

This will take the form of a column and inclined cantilevered roof section extending 5.8 metres over the verge and hard shoulder. The walls will be clad with a timber panel system and the roof section with a Perspex/GRP system. The steelwork will be protected by a protective paint system.

The estimated cost is £21.7 per km, assuming that the cantilever is installed on two sides of the carriageway i.e. some £10.9 million per km if only required on one side.

<u>Structure 2: Partially enclosed canopy</u>

This will take the form of a portal frame, with the roof section being formed from a truss. The walls will be clad with a timber panel system and the roof section with a Perspex/GRP system, with a 11.8 metre opening across the central reserve and Lane 3. The steelwork will be protected by a protective intumescent coating.

The estimated cost is £31.16 million per km.

<u>Structure 3: Fully enclosed canopy</u>

This will take the form of a portal frame, with the roof section being formed from a truss. The walls will be clad with a timber panel system and the roof section with a Perspex/GRP system. The steelwork will be protected by a protective intumescent coating.

The estimated cost is £46.2 million per km.

The above costs relate to construction activities only and a variety of other materials and combinations have been costed and provide a range of costs per kilometre for a given structure type.

The net cost of the maintenance and demolition phases has also been presented allowing for the scrap value of the steel structures at the end of the assumed 15 year Design Life.

2 INTRODUCTION

Work has been undertaken by WSP | Parsons Brinckerhoff (WSP|PB) previously on the Canopy Research and Development commission which is reported in the End of Commission Report. This stand-alone document will form an appendix of that report. WSP|PB is of the opinion that based on the combination of cost, productivity, Design Life, operational safety and maintenance, the following structural forms should be taken forward into this Structures Options Report:

- Structure No. 1: a vertical barrier with an inclined section over the carriageway;
- Structure No. 2: a structure which provides partial enclosure; and
- Structure No. 3: a structure which provides full enclosure of the carriageways;

The background to these decisions is contained in Chapters 16, 17 and 18 respectively of this report for each of the structural forms.

An appraisal of the different construction materials that may be adopted for the main structural elements of the structures is included within this report.

The flowing cladding options have been researched and considered as part of this report: timber, metal sheeting, reinforced concrete, Perspex, glass, ETFE and fabric.

The purpose of this report is to produce generic high level designs of the three structural solutions above to allow an estimate of their comparative costs to be established. This report will detail constraints surrounding the design and will investigate how the structures could be built economically. A comparison can then be made between costs for each structure type manufactured from different materials compared to the benefit it can provide in improving the local air quality.

No particular location has been specified by Highways England for the siting of the structures for the purposes of this study; rather the structures are to be suitable for typical conditions on the SRN across England. As such, a number of assumptions have been made as to the typical situation where these structures would be installed and the associated environment. These assumptions are outlined in this report and aim to be relevant to a typical location within England.

3 STAKEHOLDERS AND INTERFACES

At this time, there has been no interface or dialog with the probable stakeholders for this scheme beyond Highways England. This is on the basis that Highways England wants a high level of confidence in the outcome before making approaches to key people as listed below.

3.1 HIGHWAYS ENGLAND INTERNAL INTERFACES

Within Highways England, key stakeholders are the commissioning Air Quality Team (represented by Andrew Bean and Stephen Pyatt) and the Structures Team who are represented by Jim Gallagher, Principal Structures Advisor. As part of any internal consultation process, interfaces will be required with:

- the Commercial Services Division (in regard to cost estimates and liability)
- the Smart Motorway Programme team in regard to buildability and the probable inclusion of the additional infrastructure within the verge area, and
- Operations Directorate for considerations around maintenance, including the impact on the Traffic Officer Service.

Other stakeholders within the Highways England organisation will be those Technology and Asset Support Contractors who maintain the technological apparatus on the motorways and truck roads. These will vary from area to area and would include GeneSYS on a national basis.

3.2 UTILITIES

Utility companies may be stakeholders in the event that service diversion or reinforcement works would be required. This could include legacy apparatus left over or under the carriageway from when the original carriageways were constructed or could relate to supplies to apparatus within the highway boundary which are currently located on or just within the curtilage of the area in which air quality is an issue.

In the case of a long length of fully enclosed structure, additional reinforcement of the electrical network may be required to address the power requirements for lighting and fans should they be required by the specific design adopted.

3.3 OTHER STAKEHOLDERS

Owing to the variations in geography and local conditions in which the structures could be placed, a national list of interested parties has been prepared and includes:

- → Environment Agency;
- → English Heritage;
- → Natural England;
- → Emergency Services - via the Emergency Services Collaboration Working Group as the overarching umbrella organisation; and
- → Transport Focus.

4 GEOMETRIC CONSTRAINTS

The situation where the structures presented in this report are likely to be used is where motorways or Trunk Roads are located in close proximity to housing. These areas will typically be located on the outskirts of cities, towns and villages where the SRN will bypass communities or form a ring road.

To determine the geometric requirement of the structures, the road geometry has been assumed as that of a three lane dual carriageway rural motorway, represented by Figure 4-1a of DMRB TD 27/05 *Cross-sections and Headrooms*. However, a 2.5 metre verge width has been assumed instead of 1.5 metre verge as shown in Figure 4-1a. Increasing the verge dimension is considered necessary as these structures will be installed on existing roads and the foundations will need to avoid;

- existing services within the verge;
- drainage networks and chambers;
- communication ducting and chambers; and
- Road Restraint Systems and signage.

The increase in verge with will allow the footprint of the foundations to remain outside of the typical 1.5 metre verge width. It will also allow future maintenance and inspection of the new structure to be undertaken. Although this verge dimension is greater than the minimum shown in Figure 4-1a of TD 27/05 *Cross-sections and Headrooms,* it is not a Departure. It will, however, have a cost implication in terms of earthworks associated with the main works and increased steel required for the greater dimensions of the structures.

Due to space restriction, it is likely that the road restraint system will be specified as N2 W2, but this will have to be considered in association with other requirements in the verge e.g. drainage channels, no impact loading being imparted to the canopy structure, etc..

A sketch presenting the assumed carriageway cross section is shown below in Figure 1, a modified version extracted from TD 27/05:

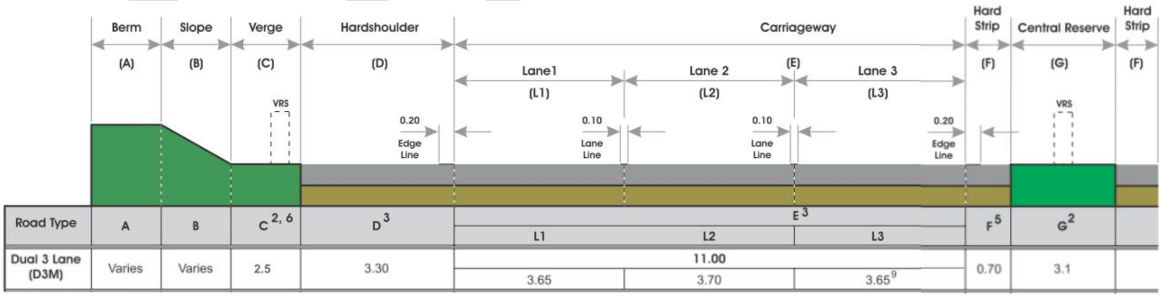


Figure 1: Road geometry assumed for design.

It is assumed that little space will exist between the edge of the road verge and housing in the instances where the barrier structures are required. This is because if there was a significant gap between the edge of the road verge and housing, the air quality limits are less likely to be exceeded due to dispersal and thus a structure like those being proposed in this report would not be necessary.

A minimum clearance of 5.7m will be used for the structure designs as per Table 6-1 of TD 27/05 *Cross-Sections and Headrooms* for structures vulnerable to vehicular impact. This clearance will be provided across the whole structure including in the verge and central reserve as per Clause 6.3 of TD 27/05 *Cross-Sections and Headrooms.*

It should be noted that if the structures are installed on a High Load Route, then the new construction headroom of 6.45 metres will be required. For the purposes of this study, a headroom of 6.45 metres is considered the exception and therefore has not been considered further in the design process undertaken. Should the greater headroom be required in certain instances on the SRN, then that will attract additional cost due to additional steelwork being required for the greater height in columns and additional cladding, which can be assessed on a pro-rata basis from subsequent work undertaken in this report.

It assumed that a column/wall cannot be installed in the central reserve to help support the partial and fully enclosed canopy. The installation of columns and/or a wall in the central reserve could affect sight lines on the road as well as the design of the standard vehicle concrete barrier provision and thus could not be applied to a typical situation in England. It would also impact on driver behaviour due to the significantly more enclosed environment it would create.

5 GEOTECHNICAL CONSTRAINTS

As no specific location has been identified for the structures, Highways England's Geotechnical Data Management System (HAGDMS) cannot be interrogated to obtain geotechnical design data that suits a specific site. Ground consisting primarily of firm to stiff clay has been used for the design and the properties of the soil are given in Table 1. These ground conditions have been selected to represent typical ground conditions recorded on and beneath highways embankments based on general experience of the network asset. In practice, ground conditions will vary from site to site, and between individual foundation locations. It is noted that this is a risk associated with the design and costing aspects of this report.

PROPERTY	VALUE
Undrained shear strength Cu	$60kN/m^2$, increasing at $10kN/m^2$ per metre below ground level.
Effective cohesion C'	$0kN/m^2$
Effective angle of friction Ø	26°
Drained modulus E'	$15MN/m^2$ to $20MN/m^2$ below 5m, and $30MN/m^2$ below 10m
Poissons ratio	0.2

Table 1: Assumed properties of ground materials used for design

Based on experience of the Smart Motorway Programme (SMP), the selection of gantry foundations has been driven by the following;

- Lateral and vertical loading;
- Available verge width;
- Speed of construction;
- Ecological constraints; and
- Local slope geometry and whether in cutting or embankment.

Whilst spread foundations have been adopted at some locations for gantry signs, their use does require a relatively large plan area, which in turn will sterilise a wider verge area. In addition, imposition of such loading at the crest of an embankment may lead to slope instability. The arrangement of piles can vary depending on the type and distribution of loading. Where a portal type structure is adopted and loads are supported on two foundations, then an arrangement of small diameter piles in a row parallel to the road is feasible. For cantilever structures, then the extra moments and lateral loads are resisted by either use of a square group arrangement or as a large diameter monopile.

A piled foundation has the advantage that it can be adopted to suit most ground conditions and is suitable in both cutting and embankment situations (noting the provision for air quality is unlikely to be required in the verge in a cutting location).

The eccentric loading and the need to provide tension and lateral resistance in the piles can restrict the use of driven piles. Helical piles have been adopted on some gantry locations; however, appropriate testing and design methodology would be required in accordance with BS 8004:2015 *Code of practice for foundations*. At the time of writing, there is some concern over the performance of helical piles, and if they are used then they would be dependent on the nature of the ground conditions.

The geotechnical certification process would need to be followed that is set out in DMRB HD22/08 *Managing Geotechnical Risk*. HAGDMS should be used at an early stage to identify likely geotechnical constraints for a particular site. Particular constraints may include areas of reinforced earth construction, soil nailed slopes areas of known instability and areas of over-steepened ground.

A constraint to foundation design is knowledge of local topography. The issue arises if the foundation is close to the crest of an embankment and a maintenance access is required behind the structure. This can lead to the need for significant retaining walls purely to provide access.

A fully enclosed Structure No. 3 is likely to shed a significant amount of concentrated surface water. This will need to be collected and prevented from affecting the geotechnical asset in an uncontrolled manner which could affect slope stability.

A summary of the foundation solutions is presented in Table 2.

FOUNDATION METHOD	ADVANTAGES	DISADVANTAGES
Spread foundations	→ Ease of construction, no specialist contractor required.	→ Large footprint area required. → Requires competent ground near to ground level. → Large amount of arisings generated.
Bored cast insitu piles/ CFA piles	→ Smaller footprint area required to install foundations. → Smaller volume of arisings generated. → Able to penetrate a wide variety of ground conditions. → Quick installation and programme benefits → Reduced ground risk	→ Flighting of granular material may occur. → CFA installation method may find it difficult to penetrate hard ground. → Large piling plant working close to the live carriageway
Driven piles	→ Minimal spoil generated. → Quick installation.	→ Difficult to penetrate through hard ground conditions. → Installation method generates vibrations and noise. → May have limited tension or lateral load capacity.
Helical piles	→ Minimal spoil generated. → Quick installation.	→ Difficult to penetrate through hard ground conditions. → Individual pile testing required. → Design certification may be difficult → May have limited lateral load capacity.

Table 2: Summary of foundation solutions

For the purpose of this study, piled foundations have been chosen. The use of piled foundations will affect the geotechnical asset to a lesser extent than spread footing and will be less dependent on the properties of the soils that form the embankment earthworks. For particular schemes, a strategy could be developed to determine the appropriateness of spread foundations when compared with piled foundations; however at this stage it is considered prudent to assume that piled foundations will be required. In addition piles can be installed in a wide variety of ground conditions across the length of the route and minimise the space required to install the foundation.

6 ENVIRONMENTAL CONSTRAINTS

As no specific location is being considered, it is not possible to provide in detail the environmental constraints affecting a particular site. For the purposes of this study, it is assumed that no environmental constraints exist or affect the design with the exception of the need for air quality mitigation. As the design progresses, however, then the following parameters will need due consideration:

- Construction Impacts
- Air Quality(in detail)
- Ecology and Nature Conservation
- Geology and Soils
- Heritage and Historic Resources
- Watercourses and Drainage
- Landscape and Visual Effects
- Noise and Vibration
- Effects on Non-Motorised Users and Communities
- Cumulative Effects

It is expected that the air quality will deteriorate locally on the approaches to the partial and fully enclosed structures as there will be a concentration of pollutants emanating from the structures at these open ends. It is assumed that the approaches to the structures can be positioned in areas beyond residential properties where this higher concentration of pollution is acceptable. No allowance has been made in the costings for any extra air cleaning using filters etc prior to the air from within these structural options, Structure No. 2 and 3, being released into the atmosphere.

7 EXISTING STRUCTURES

It is highly likely that the proposed structural options will be required to integrate with some form of existing structure during their length, whether that is a retaining structure or bridge. Should this be the case, the existing structure will need a full assessment to determine its capacity to receive the optimum canopy/tunnel type option. At this stage of the study, no further consideration is given to siting the canopy on an existing structure as this will need to be considered on an individual site by site basis.

As well as the proposed canopy crossing existing structures, it is also likely that some existing structures may also need to be demolished to accommodate the new canopy. The list of other potential structures requiring demolition include legacy MS2 and MS3 signs and bases, gantries which would have been incorporated into previous safety or capacity works on the section of SRN associated with the new canopy/tunnel type structure provision, large Advance Direction Signs and bases, CCTV installations, etc.

8 PROPOSED STRUCTURE MATERIALS

8.1 CONSTRUCTION MATERIALS

Reinforced concrete, timber and steel were considered as possible construction materials for the main structural members of the proposed structures (excluding the cladding associated with the vertical wall and roof components). Table 3 show a list of the Pros and Cons for each material.

MATERIAL	PROS	CONS
Reinforced concrete	→ Material cost are typically cheaper than steel. → Low maintenance required. → Good fire resistance and durability.	→ Sections are typically large in order the get required strength sections required. → Construction is slower than other materials with site construction time prolonged → The structure will be heavier and result in larger foundations. → Limited prefabrication opportunity as in-situ stitching will be required between pre-fabricated elements.
Timber	→ Lightweight → Material costs are typically cheaper than steel and concrete.	→ Poor fire resistance. → Short design life. → High maintenance. → Low material strength leading to large sections and possible closer frame spacing being required.
Structural steel	→ Lightweight → Able to be prefabricated making installation on site fast and easy. → High strength. → Smaller section sizes can be used compared to other materials. → Smaller foundations can be used compared to a concrete structure.	→ Material cost are typically more expensive that other materials. → A protective coating will be is required to provide fire resistance. → A protective coating is required to provide adequate durability.

Table 3: Pros and cons of potential material for main structural elements

The following three criteria have also been considered, in addition to the pros and cons, to appraise which construction material is the most appropriate for the main structural elements of these structures:

- → Disruption to carriageway traffic is to be minimised as much as possible during construction.
- → The structures should be as aesthetically pleasing as possible whilst also considering economy.
- → Whole of life cost of the structure.

Considering the above driving criteria and the pros and cons of each material, steel has been chosen as the most appropriate material for the main structural elements. The reasons for this are listed below:

- Steel lends itself well to speedy construction as most, if not all components, can be prefabricated in sections and bolted together on site. The canopy will likely have many identical elements that are well suited to prefabrication, therefore increasing quality control and minimising the risks of site works. This gives steel a distinct advantage over concrete which would take significantly longer than steel to build, increasing traffic disruption and increasing the risks of onsite work.
- Out of the three materials, the most slender elements will be achieved by using steel, with timber and concrete members likely to be significantly larger. Steel will, therefore, minimise the land take required.
- Although the material cost of steel is often higher than the other materials, it is expected that the speed and ease of construction, along with the prefabricated sections, would lead to significant savings in construction when compared to concrete. Also with an appropriate protection system, steel can offer sufficient durability and fire resistant for the design life with little or even no maintenance required, giving it an advantage over timber.

9 FIRE REQUIREMENTS

9.1 DESIGN STANDARDS

A full fire risk assessment is beyond the scope of this study, however, consideration is given here to fire requirements and the mitigation measures necessary to reduce risk to life in the event of fire or other emergency situation, particularly within the partially/fully enclosed canopy structures. The associated costs will be included in the reported figures for the options later. The heat from fire has the potential to impact on structural integrity over a given period of time and there is the potential for high concentrations of poisonous gases due to burning of vehicles and unknown cargo. This is particularly true in the case of Structures No. 2 and 3 where the extent of structure over the carriageway has a much greater effect on the health and safety of both maintenance contractors, emergency service response and the travelling public.

Discussion will be required with the Technical Approval Authority (TAA) to determine fire ratings and the standards which will govern fire safety for all options, but for Structures No. 2 and 3 in particular. Consideration was given to adopting DMRB BD 78/99 *Design of Road Tunnel*, however, the definition of a tunnel in the same standard is given as "*A road tunnel is a subsurface highway structure enclosed for a length of 150 metres, or more.*" As neither Structure 1, 2 or 3 will be subsurface, it is not considered that this standard is wholly appropriate for this situation. It has, however, still been consulted for elements of fire consideration, such as emergency exist spacing and ventilation requirements.

With regard to Structure 3 (fully enclosed canopy), the PIARC *FIRE AND SMOKE CONTROL IN ROAD TUNNELS* document has also been consulted, as it is likely that some sections of the structure will be greater than 150m in length. This PIARC document details common practices for various countries and establishes international best practice and would be consulted as design develops. The principles established within this design guidance have been utilised in the costings work associated with Structure No. 3.

The *Approved Document B; Fire safety - Volume 2 Buildings other than dwelling houses* would apply with regards to Buildings Regulations. By adopting this standard, Structure 2 and 3 may be defined as a single storey building, and as such, they wouldn't necessarily require additional fire protection. There are exceptions, however, such as where the external wall of the structure must retain stability to prevent fire spread to adjacent buildings. As no site specific location is being considered, it is assumed that in a typical situation this boundary condition need not be applied.

Consultation will be required with the TAA and emergency services to determine the most appropriate fire requirements given the unique circumstances of the structures, in particular for Structure 2 and Structure 3.

9.2 FIRE PROTECTION RATING: STRUCTURE 1

Based on the material appraisal in Chapter 8, the main structural members of the canopy will be steel.

Structure 1 is not considered to require any further fire protection other than the 15 minutes offered by the unprotected steelwork itself as sufficient means of escape exist in the event of a fire to areas which are not adjacent to or under the cantilever section.

9.3 FIRE PROTECTION RATING: STRUCTURE 2 AND STRUCTURE 3

The possibility of a fire resulting from multiple vehicle incident or other emergency exists, where a timely escape/evacuation may not be possible from Structure 2 and 3. In such a situation, sufficient time for emergency service response and action may be required, along with the time required to evacuate that enclosed area, taking into account physical conditions e.g. gradients and the length of the structure, reduced mobility persons within the stationary traffic and the possible difficulties in moving injured road users . Discussion with emergency services and the TAA will therefore be required to determine fire protection requirements, however, for the purposes of this study, and ascertaining an estimated cost per structure, a fire protection requirement of 60 minutes is deemed appropriate.

9.4 FIRE PROTECTION SYSTEMS: STRUCTURE 2 AND STRUCTURE 3

It is proposed to reduce the fire hazard from the canopy/tunnel type structure itself by constructing it from non-combustible or fire retardant materials where possible and appropriate.

The fire protection of Structure 2 and Structure 3 may be achieved through a variety of forms, such as boards, concrete encasements, blankets, sprays or intumescent coatings. However, the structure itself will likely be subjected to a fairly aggressive environment which will impact the choice of fire protection. The steelwork will likely be subjected to cyclic wet/dry, unprotected from the effects of moisture introduced to the canopy from the open ends of the structure and from the vehicles. Furthermore, the steelwork will be subjected to salt spray during the winter as a result of carriageway gritting operations.

Fire protection boards are not considered appropriate in this situation. Although they can be used in external environments, this is not normal practice and Structures 2 and 3 are not where the boards are best suited. Furthermore, the boards will introduce hidden elements in this instance making the members difficult to inspect.

Cementitious fire protection sprays are also not considered appropriate in this instance due to the poor aesthetics of the system. The system would also add unwanted super-imposed dead load to horizontal members and make connection of cladding to the columns more challenging as flush finishes can be difficult to achieve.

Fire protection through concrete encasement has potential for the columns of the structure as the concrete adds durability, being more resistant to impact damage and weather exposure. However, the concrete protection adds space requirements and has increased cost implications when compared to lightweight systems. Visually, it will be less appealing to the (transient) driver. Concrete encasement would not be suitable for horizontal roof members.

Web infilled columns may also provide suitable fire protection, where normal lightweight poured concrete is fixed between the flanges by shear connectors attached to the web. This system could provide up to 60 minute fire protection.

Fire protection blankets are not considered suitable in this instance as they will likely further reduce the aesthetics of the structure.

Intumescent coating fire protection can be applied in either thin film or thick film. Normally, thin film coatings would be suitable for internal situations where the environment is normally less aggressive than external situations. Thick film coatings would normally be considered for external environments and even in marine environments. Refer to Chapter 10 *Durability* for further discussion on intumescent coatings which is the proposed WSP|PB optimum provision to address fire protection requirements.

There is the opportunity for intumescent coatings to be shop applied on pre-fabricated sections, whereas the remaining fire protection systems will be site applied.

9.5 EVACUATION: STRUCTURE 2 AND STRUCTURE 3

In the event of an emergency, it is proposed that alarm lights and sirens activate to alert canopy occupants to evacuate as quickly as possible through emergency exits which will need to be provided. A pedestrian flow modelling exercise will be required to understand people movements in the event of fire or other emergency and where emergency exits will be best situated to ensure evacuation is achieved in suitable time. For the purposes of this study, an exit spacing of 100m on both sides of the road will be assumed, taken as a reasonable spacing based on tunnel provision requirements given in Clause 3.16 of BD 78/99 *Design of Road Tunnels*. It is assumed that there will be sufficient space for an escape route to the external face of the canopy walls (Structure 2 and 3) for those people using the emergency exits, either behind the vertical wall or up/down the earthworks slope.

It is proposed that the emergency exits will take a similar form to that shown in Figure 2 below, taken from Figure 2 of BD 78/99 *Design of Road Tunnels*. The provision would also act as maintenance accesses.

Consideration will need to be given to the impact on people who are less physically able – and an Equality Impact Assessment will need to be considered.

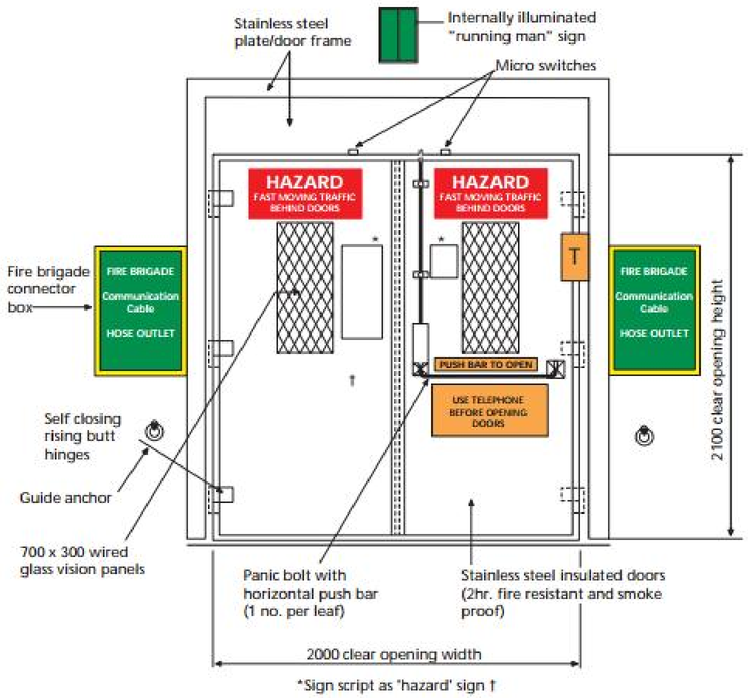


Figure 2: Elevation of typically exit point to be installed along canopy walls

9.6 VENTILATION: STRUCTURE 2 AND STRUCTURE 3

For Structure No. 3, a ventilation system will be required for the fully enclosed canopy/tunnel type structure to limit the build-up of poisonous gases when its length exceeds 450 metres. It is assumed that this will be in the form of fans positioned along the tunnel, to push the smoke and gases to the nearest open end of the tunnel. A tunnel ventilation model will be required to understand the number of fans required and this is out with the scope of this study.

Most tunnels benefit from the longitudinal air velocity induced by the traffic (the “piston effect”) to aid with ventilation where the tunnels are uni-direction. As Structure 3 will essentially be bi-directional, as traffic will move in opposite directions on each carriageway, it is likely that “piston effect” will be reduced/destroyed and will probably not contribute to ventilation of the structure.

Refer to Chapter 14 *Actions* which details the assumptions in terms of fan load for the purposes of creating a structural model of the proposed canopy.

It is assumed that in the partially enclosed canopy (Structure No. 2) that the open roof section of the canopy will provide adequate natural ventilation to satisfactorily limit the build-up of the poisonous gases and therefore mechanical ventilation by fans will not be required.

Provision for ventilation will be made in the cost estimate associated with Structure 3 later work.

10 DURABILITY

10.1 DESIGN CRITERIA

BD 7543:2015 *Guide to durability of buildings and building elements, products and components* defines durability as the ability of the building and its parts to perform its required function over a period of time and under the influence of agents.

For the purposes of this study, the design life of the structures (Structure 1, 2 and 3) is taken as 15 years as per the discussion with Highways England.

10.2 GALVANISATION

All structures (Structure 1, 2 and 3) will need to be protected by some method to limit corrosion. Galvanised members have been considered, however, the member sizes or section of frame will be restricted by the galvanising bath sizes available.

It is envisaged that the structures (Structures 1, 2 and 3) will be largely prefabricated off site and members welded where possible to improve aesthetics and limit the use of bolts. Off-site prefabrication will reduce site works and associated temporary traffic management and risks, whilst increasing the quality of the workmanship where welding and assembly is undertaken in controlled environments.

The size of the prefabricated parts will be limited to that which can be transported by road, therefore, it is proposed that construction joints will be necessary in the frames of Structures 2 and 3 to allow for transportation. These construction joints will require connection on site to complete the frames.

The construction joints between prefabricated sections of frame will then need to be bolted so that the galvanised coating is not damaged by welding. Bolted connections will also reduce hot works requirements on site, but conversely bolts can be considered as impacting aesthetics where these splices exist. The quality of on-site welding and touching up of galvanising will need particularly careful control mechanisms to ensure they provide the desired strength and finish criteria.

Additionally, should galvanising be adopted for corrosion control, a separate system would also be required to provide fire protection also for Structure 2 and Structure 3.

10.3 PROTECTIVE PAINT SYSTEM: STRUCTURE 1

It is proposed that corrosion protection for Structure 1 is achieved through use of a protective paint system as no further fire protection system is required.

10.4 INTUMESCENT COATINGS: STRUCTURE 1, 2 AND 3

For the purposes of corrosion protection, and alternative to protective paint systems and galvanising would be through the use of intumescent coatings. The intumescent coating would also provide fire protection as discussed in Chapter 9*: Fire Requirements*, which wouldn't be necessary for Structure 1 but are considered appropriate for Structure 2 and Structure 3 as they can provide a twofold function of corrosion and fire protection.

Intumescent coatings, particularly of the thick film type, can provide corrosion resistance for up to 20 years, even in aggressive environments. If such a product were adopted, no further steelwork protection systems would be required. Thin film intumescent coatings can also provide corrosion resistance but less effectively where the environment is aggressive. This may mean that a thin surfacing may require replacement during the anticipated design life of the structure and so due to the associated cost of delay to the travelling public and dangers associated with the installation of traffic management and then subsequent installation of the coating at height, the thin option is discounted here for the Structure No. 1 and 2 structures. On the basis that the partially enclosed canopy and cantilevered canopy will also be subjected to an aggressive environment, a thick film intumescent coating is recommended for the full length of these structure options.

Roads are classified as a C5 environment. A product such as FIRETEX M95 or potentially FX6000 both of which are intumescent coatings from Sherwin-Williams would provide both corrosion and fire protection for up to 15 years and 120 minutes respectively in a C5 environment in accordance with BS EN ISO 12944-2. The M95 technology is typically used on offshore installations and subjected to the harsh North Sea conditions, so have a good track record of proven performance in extremely aggressive conditions and do not require the topcoat to achieve this durability (although always are topcoated for aesthetic reasons).

Both of these products (M95 and FX6000) are actually very low in terms of their VOC (both <100g/L as per Sherwin-Williams technical data sheets), although any topcoats would be higher and any solvented coatings, or any coatings applied by spray, would require care and attention.

It is noted that loading allowances for the weight of coatings would need to be taken into account in the design of the final structure when it advances in its design life cycle.

11 ARCHITECTURE AND FINISHES

11.1 OVERVIEW

It is an inevitable consequence that the provision of a canopy/tunnel type structure will have a visual impact on the occupiers of nearby properties i.e. the receptors being protected from unacceptable air quality and to a lesser amount on the transient driving public. The structure will be obvious in the landscape due to its height requirements as stated above. If it is an urban situation, the impact will be lessened by the surrounding urban landscape.

11.2 AESTHETIC CONSIDERATIONS

This section covers the manner in which the structure itself can be reduced in its impact.

In the case of the cantilevered canopy (Structure No. 1), the height of the barrier is determined by the headroom clearance required and this cannot be altered without a Departure from Standard, of which no reasonable justification for doing so can be presented here. The pitch of the roof section will be kept to a reasonable value of only some 10 degrees to mitigate the overall height of the structure without attracting excessive design load penalties.

The angular nature of Structure No. 1 could be mitigated through use of curved sections to smoothen the interface between the vertical and cantilevered roof sections. This may give a more aesthetically pleasing profile to the structure, however, this approach will likely increase fabrication costs so is not considered in this study.

For the partial enclosure option (Structure No. 2), the headroom clearance criteria remains in place whilst the roof section will be significantly longer, resulting in the top being at a higher level. To reduce the forces exerted on the structure, one option considered was the use of a regular stay wires to provide stability to the roof section through an anchorage provided within the earthworks to the external face of the structure. This option is investigated and discussed later in this report.

In the case of the partially and fully enclosed canopies (Structure No. 2 and 3), two principal options are available to the designer, a portal frame type structure with a flat or pitched roof or a large arched structure. Flat roofs inherently suffer from maintenance issues and are not considered suitable for such a large span, in particular where deflection will be notable and may cause ponding water. Although a pitched or curved roof will extend to a greater height and may be more noticeable to surrounding properties, it will likely give a more aesthetically pleasing profile when compared to a flat roof. An obvious advantage of the pitched or curved roof option is that if the space is available to place extraction fans/blowers in the space created by the curved profile. An arched structure could be considered more aesthetically pleasing, but will likely cost more than a portal frame and will have a larger landtake requirement.

From feedback for a scheme in Poland, it is recommended also that additional structural elements are included to help break up snow and reduce the tendency for it to lodge on the upper surfaces. Such flanges will add to the shape of the structure provided.

Opportunities exist to make the features (Structure No. 1, 2 or 3) into statement structures. In the light of their relative short Design Life, however, and the need to maintain as minimal cross section to keep costs down and physical room required for foundations, etc in the verge, this aspects is not advanced in this SOR but are described below.

Concepts such as different vivid colours used for the inside of the features should be considered also so that they have an identity and become a location trigger for drivers. It is suggested that, subject to the outcome of stakeholder consultation, the outside of the structures are kept as the natural colour of the components e.g. timber or grey/pastel colours to maximise their ability to blend into the background.

Other concepts could be printed images on the external surfaces of what was visible prior to the installation of the structure (Structures 1, 2 or 3) or the use of the "dazzle camouflage" effect. Both these concepts have been discounted at this time but can be further investigated depending on future feedback. There would be a limited cost implication of such provision for the Design Life involved.

A further consideration is whether the materials used are suitable for painting. If so, a matt finish to reduce any glare and/or reflection is recommended for the inside of Structure No. 2 and 3. Alternatively for those products which can be easily coloured – Perspex, glass, Ethylene Tetrafluoroethylene (ETFE, a film used either as a single sheet or pneumatic cushions which is prone to puncturing by sharp objects but is an excellent roof material) – the choice of a colouring agent will be important with regard to the effect that it is planned to provide. There will be differing points of view in regard to colours as

- the provision of coloured surfaces will reduce the amount of light which will enter the partial or fully enclosed structure (Structure No. 2 and 3) which may have on impact on the quantum of lighting required; and
- any colours or patterns used must not cause distraction for the drivers due to the potential for an increase in accidents adjacent to or within the structures.

11.3 FINISHES / CLADDING

Several possible cladding materials have been investigated as part of this study. Table 4 overleaf provides a comparison of the cladding materials considered and their relative advantages and disadvantages.

As well as the relative pros and cons above, the final choice of cladding material will be heavily dependent on Highways England's preferences. In the absence of having a detailed discussion with Highways England regarding cladding, the main driver is taken to be economy and safety.

For all structures (Structure 1, 2 and 3), it would therefore be advantageous if the products selected for cladding are readily available in the market rather than manufacturing process having to be created for the sole purpose of these canopy/tunnel type structures. It is also necessary that the cladding panels can be made air tight to satisfy the Highways England requirement. It is anticipated that the outer surfaces of the structures would be relatively smooth to reduce the ability of snow to lodge on them, to make them more difficult to climb upon and easier to clean.

Although standard **timber** acoustic barriers are available in the form of panels 2.4m wide, such as Jacksons Fencing (https://www.jacksons-security.co.uk/acoustic-security-barriers/highway-noise-barrier.aspx.), these would require modification to be suitable for the purposes of acting as an environmental barrier e.g. by applying mastic to make airtight. It is suggested instead that timber panels for this application of environmental barrier to Structure 1, 2 and 3 be constructed with plywood facing, with mastic applied to the joints to make airtight. Timber favours well in comparison Table 10.1, although it is noted that it will not allow the passage of light. It is therefore proposed that timber panels be considered for the wall section of the structures only and a transparent material adopted for the roof section to allow natural light to enter the structures.

Material	Suitable for different form of enclosure anticipated			Beneficial lighting implication	Land take implications	Visually intrusive post mitigation	Assessed carbon footprint	Difficulty in coping with existing/planned furniture
	Cantilevered	Partially enclosed	Fully enclosed					
Timber	Yes	Less so	Less so	No	Medium	Low	Low	Low
Metal sheeting	Yes	Yes	Yes	No	Medium	High	High	High
Reinforced concrete	Yes	Yes	Less so	No	High	High	Medium	High
Perspex	Yes	Yes	Yes	Yes	Medium	Low	Medium	Medium
Glass	Yes	Less so	Yes	Yes	Medium	Low	Medium	High
ETFE	Yes	Yes	Yes	Yes	Low	Medium	Medium	Medium
Fabric	Yes	Less so	Less so	Unlikely	Low	Medium	Medium	Low

Material	Anticipated construction cost	Suitability for short design life	Susceptibility to Vandalism / graffiti/ security	Ease of maintenance, operation, repair	Anticipate maintenance costs	Comments
Timber	Low	Yes	Medium	Low	Low	Familiar product, prove record
Metal sheeting	High	No	Low	Low	Low	Theft, weight, systems available
Reinforced concrete	High	Medium	Low	Low	Low	Increasingly heavy, pre-casting option
Perspex	Medium	Yes	High	Low	Medium	Vandalism, ease of damage,
Glass	High	Medium	Medium	Medium	Medium	Weight, replacement, ease of damage
ETFE	Medium	Yes	Medium	Medium	Medium	Pollutants if burnt, discolouration
Fabric	Low	Yes	High	Low	High	Ease of damage, jointing issues

Table 4: Comparison tables extracted from the End of Commission Report

Metal sheet noise barriers are also currently available in a variety of forms, textures and colours which could likely be modified to act as an environmental barrier with relative ease. It is proposed that if sheet metal panels are adopted, they should contain a matt finish to reduce light reflection from headlights, lighting associated with emergency or maintenance vehicles or the sun, all of which may cause driver disorientation. Metal sheeting is perceived to be comparatively more expensive than timber panels, although this is investigated further in *Chapter 20: Cost Estimate*.

Reinforced concrete panels also come readily available, such as Gramm's Concrete Absorptive Noise Barrier Panels (http://www.grammbarriers.com/downloads/ConcreteAbsorptiveSpecificationSheet.pdf). However, these are significantly heavier than either the timber or metal sheeting options and would clearly be considered for the wall sections only. It should be noted that concrete panels would also normally be appropriate where a significant design life is being aimed for, however, in this instance where only 15 years is being targeted, concrete is unlikely to be appropriate. It is, however, investigated in *Chapter 20: Cost Estimate* so a cost comparison can be made.

Perspex or Glass Reinforced Plastic systems are also readily available, such as Smyth Composites Impact Resistant Fybaglaze GRP glazing system (http://www.scomp.co.uk/grp-product-range/grp-impact-resistant-anti-vandal-glazing/). This type of system is considered durable and versatile, whilst also being significantly lighter than glass. It can be susceptible to graffiti, however, so would be more suitable for the roof sections only. A system such as this on the roof section would then also allow natural light to enter the structures (Structures 1, 2 and 3), making them feel more open and reducing the requirement for artificial lighting. A Perspex or GRP glazing system is therefore considered an appropriate solution for the roof section along with a timber panel type system for the wall cladding sections.

As **glass** is considerably heavier than Perspex or a GRP glazing system, it is not considered appropriate for this application as the supporting frame for the cladding system will need to be greater to accommodate the extra weight when compared to Perspex or GRP, therefore attracting additional cost. Glass cladding costs are investigated in *Chapter 20: Cost Estimate*.

Although **ETFE** has the potential to provide excellent architectural finishes and profiles for roofs, it requires constant pressurisation and therefore the need for its own air pumps and associated services. These services attract on-going maintenance and it is considered at this stage that it would be Highways England's preference to avoid systems which require on-going maintenance. It releases the extremely corrosive and toxic hydrofluoric acid on combustion. It is further noted that the material does not provide any noise abatement and so if air quality problems exist in association with noise problems, increased barrier provision would be required. Additionally its Design Life is well in excess of that being required for this study. ETFE is not considered further in this study as an appropriate cladding system but is included in pricing for comparison purposes.

Fabric as a cladding material (as illustrated typically in http://www.clearspan.com/) was initially considered as an appropriate covering system but not developed in detail because:

- they are normally associated with light weight structures which are not suitable for the aggressive environment around the SRN (hence cost savings associated with lightweight structures would not apply);
- concerns over their behaviour in a fire;
- the need to accommodate heavy tunnel operations and maintenance equipment within it (again impacting on the lightweight structure);
- susceptibility to vandalism; and
- difficulties with the inspection of the outer/external faces;

However, given the high cost of the other more traditional solutions, it may be worth investigating the cost viability of a lightweight fabric covered structure:

- For lengths shorter than 150 metres where mechanical and electrical equipment is not required as the structure would not be a tunnel (BD 77/98 Design of Road Tunnels Clause 1.2);
- if a feasible solution to the external inspection can be agreed e.g. through the use of unmanned aerial vehicles or drones; and
- Risks associated with fire and vandalism could be mitigated or considered acceptable.

Based on the above appraisal, it is suggested that timber panel wall cladding and a Perspex/GRP roof cladding system is the most appropriate combination for the purposes of the three canopy/tunnel type structures. These cladding options are therefore adopted for the purposes of producing a model of the structures as discussed later in this report i.e. they will act as the base cases. The costs of the other cladding options are investigated In *Chapter 20: Cost Estimate* so comparisons can be made with appropriate allowances being made in steel quantities to reflect their self-weight in comparison with timber or Perspex.

It is noted that both ETFE and fabrics may have a 'rippling' effect generated within the material in certain conditions unless tensioned. This could have the ability to be a potential driver distraction.

12 DRAINAGE

It is the aspiration that the structures are as maintenance free as possible. It would therefore be the aspiration to avoid the use of guttering and down pipes the structures as these have a tendency to block and require regular cleaning. It is understood, however, that a positive drainage system in the form of guttering and downpipes cannot be avoided in all situations. Such situations would be where there is limited space to the rear of the canopy or where the motorway is in steep cutting, for example.

As no particular location has been specified for Highways England to consider, a conservative approach is taken to assume that for a typical location in England, a positive drainage system will be required. A positive drainage system has therefore been assumed for costing purposes along with the associated maintenance activities during the life of the structures.

It is proposed that the positive drainage system would take the form of a gutter typically of a size 300 millimetres wide and 200 millimetres deep, connected to downpipes at approximately 24m intervals which will discharge directly to the existing drainage system. Rodding eyes will need to be included at the change in directions of the downpipes and appropriate manholes included to address blockages. The gutters will need regular maintenance throughout the year, in particular during autumn, to remove blockages and ensure the drainage system remains effective.

In situations where guttering and downpipes can be avoided, it is proposed that precipitation run off from the roof sections of the structures (Structure 1, 2 and 3) be allowed to fall to the rear side of structure walls where it will be collected by a French drain. For this scenario to be realised, sufficient space will need to exist for the siting of a French drain, typically 0.6 metres wide or so and containing a perforated pipe and the associated room for its maintenance. The pipe would then discharge into the existing drainage regime associated with the SRN asset. The existing road drainage system should be adequate as the catchment area remains the same however it will need to be checked to ensure this. Staining of the cladding by the run off would be minimised by a roof overhang to the external face of the structures.

13 CONSTRUCTION, MAINTENANCE AND OPERATION CONSIDERATIONS

13.1 SAFETY GOVERNANCE

Safety Governance is a key aspect for Highways England – requiring the development of appropriate Major Project's Project Control Framework safety products – Safety Plan, Maintenance Repair Strategy Statement, and so on. This will need early engagement with the Highways England Professional Technical Service team. If the scheme is considered novel and introduces significant risks then presentations to the National Safety Control Review Group will be necessary (see Interim Advice Note 191/16), linked to the Safety Plan to the scheme category that defines the safety governance requirements. There will be a need for a GD 04 process to be undertaken, to report safety risk assessment on any options advanced to detailed design.

13.2 PROVISION OF ROAD RESTRAINT SYSTEM

The walls of the structures will be protected by Road Restraint Systems to minimise damage but they still may be a need to repair or replacement.

13.3 ACCESS AND MAINTENANCE LOADING

The structures will be largely maintenance free for their short Design Life; however, access will be required for inspection purposes and to allow for any unforeseen repair work or cleaning. It is proposed that the vertical sections of all structural solutions would be inspected through temporary access means such as ladder, zip up scaffold or Mobile Elevated Working Platform (MEWP). Access to the external faces of the canopy could be gained through the emergency fire exits as discussed in *Chapter 9: Fire requirements*, with parking on the hard shoulder proposed under appropriate traffic management. The same methods would be suitable for inspecting the internal roof sections also.

It is anticipated that the external face of the roof of all structures could be inspected and maintained by a worker on top of the roof, gaining access from the outside of the canopy via permanent ladders installed near the maintenance access points. The roof of all structures will need to be designed for maintenance loading, refer to *Chapter 14: Design Actions*. Harness anchor points and a horizontal lifeline system is allowed for on the roof of the fully enclosed option to allow maintenance personnel to traverse the roof safely as the upper surface is not accessible from below. In the case of fabric or ETFE roofing, specialist safety walkway access may be required due to the nature of the material.

13.4 MAXIMISING MAINTENANCE ACTIVITIES PER VISIT

As with any inclusion of an asset on a modified part of the SRN, the approach to maintenance adjacent to or within the structures must be considered. To utilise temporary traffic management to best effect, a wide range of maintenance activities should be undertaken within any individual closure e.g. signals and gantries. The imposition of a blockade instead of temporary traffic management may well become the favoured method of working.

13.5 COMBINATION OF WET AND DRY CARRIAGEWAYS

All structural options raise the issue of drivers moving between wet and dry lanes of carriageway in the event of precipitation.

For Structure No. 1 and 2, drivers in Lane 1 could be driving on a relatively dry road compared to the remaining lanes which are uncovered and could be saturated. For Structure No. 3, the carriageway inside the canopy will likely be drier than that exposed to the elements; therefore a driver would emerge from the dry canopy onto a saturated carriageway.

In all cases, the difference in grip may cause loss of control and would have to be an issue looked at in terms of signing and improved driver education in association with seeking advice of the Road Safety auditors and emergency services. It is noted, however, that moving from saturated to dry carriageway is not an uncommon situation on the SRN at present where overbridges or tunnels are in existence which offer precipitation protection of the carriageway.

13.6 EXCLUSION OF LOUVRES

With due regard to the need to maximise the air tightness of the full enclosure structures, it is not anticipated that louvres would be included at this time. It is also noted that the use of mechanical opening devices and electronic sensing equipment would significantly increase the fit out and operational costs as well as the construction cost due to increased dead weight. Accordingly they are not considered further in this commission.

In the case of the partial enclosure or fully enclosed canopy, the movement of air within these particular structures could be increased through the provision of a narrow opening at the base of the vertical wall (i.e. a horizontal slot above the foundation level, maintained to be free of detritus and vegetation). In principle, the hotter air above the road surface (from the black surfacing, road/tyre friction and engines) will naturally rise and this upward movement would be fed from air entering from outside the structure through the above mentioned supplied slot. It is noted, however, that such a provision renders the cladding non-airtight and as such it is not investigated further at this stage. However, it may be worth including in air flow modelling in future also it would reduce noise mitigation benefits, being located at the level of the tyre/road interface.

13.7 IMPACT ON EARTHWORKS ACCESS

It is noted that the structures will reduce the access to their rear i.e. increase isolation of the earthworks although this is to be mitigated by the provision of maintenance gates (doubling up as emergency exits). It is noted that part of the routine inspection of the route will need to include these doors to ensure that they are not left open by maintenance personnel, members of the public or vandals.

13.8 MODULAR DESIGN AND SPARES

The support and cladding systems used on the structures should be modular in its design concept and sufficient stock kept so that third party damage can be readily and quickly repaired or replaced.

13.9 OTHER IMPLICATIONS OF LONGER FULLY ENCLOSED OPTIONS

Accepting the fact that the fully enclosed option (Structure No. 3) is technically not a tunnel as it is above ground, longer Structure No. 3 provision will likely require use of a Supervisory Control And Data Acquisition system (SCADA) of ventilation and lane control. There may, however, be interface issues on an operational regime which has variable use of the hard shoulder.

It is unclear at this time if longer fully enclosed canopies (Structure No. 3) would necessitate the inclusion of specific conditions as currently recognised for major tunnels e.g. Dartford or Tyne Tunnel. These may include restrictions on certain vehicles such as height (although the option outlined has indicated sufficient headroom for over height vehicles) or those carrying dangerous loads which may require an escort; and provision for a vehicle recovery service. The current National Vehicle Recovery Manager (NVRM) service may be sufficient for this latter provision.

It is assumed that the provision of any air quality mitigation activities in the form of Structure No. 3 will be part of a greater project and as such adopt Highways England tunnel standards.

If the mitigation provision is a requirement within a Smart Motorway scheme, the possible provision of Emergency Refuge Areas (ERA) within the structure should be considered as detailed in IAN (Interim Advice Note) 161 Smart Motorways (Paragraph 2.5) and subject to a GD04 risk assessment (DMRB Volume 2 Section 2 Part 3).

Very long enclosed canopies (Structure No. 3) may have difficulties with air quality discharge if ventilating at set locations is required to be implemented. With the structure defined as a tunnel for the purpose of this report, additional inspections in relation to emergency equipment, ventilation and lighting will be required.

13.10 DRAINAGE

The provision of guttering to all the structures will introduce a maintenance liability in the form of cleaning and inspection. The view of this study, however, is that a positive drainage system is required for the structures to protect the earthworks and carriageway foundation assets. Their placement on the rear of the proposed structures would reduce the need for temporary traffic management although vehicular access will remain a requirement for operatives and hand equipment.

13.11 SECURITY

A solid bottom section of the structures limits visibility from the carriageway either by passing drivers, maintenance personnel or the emergency services. This will help vandals, thieves etc. to remain out of sight. A translucent cladding at the bottom section of wall may help discourage antisocial behaviour or cable thefts near the structures.

13.12 INTERACTION WITH OTHER PROVISIONS IN THE VERGE CROSS SECTION

IAN 149 sets out the existing minimum motorway requirements. Therefore these should be considered for the inclusion of the canopy structure within the verge. Likewise, if the structure is included within a Smart Motorway scheme, the requirements of IAN 161 should also be considered. Additional checks will also need to be carried out in relation to the visibility associated with any CCTV system and sign and signals. A verge of 2.5 metres width is proposed which may require localised widening for any existing verge provision and therefore have a cost implication. These costs have been indicatively included in the cost estimate.

13.13 ROAD SURFACE TEMPERATURES

At this time, it is not clear what the effect of a canopy/tunnel structures will have on the road surface temperature. It could be warmer or colder under the canopy under different weather conditions after frosts or due to localised greenhouse effect in the canopies. Additional provision of road surface sensors may be needed to detect icy conditions (most likely the non-intrusive type which could be fixed to the canopy frame). A review of precautionary treatments for these sections of carriageway may be required with the maintenance contractor prior to implementation of the optimum structure for a given specific location.

13.14 SNOW PLOUGHING AND RESIDUAL MATERIAL

There will be potential issues with respect to the number of lanes which are covered by the canopy, which could result in one lane being clear of snow and the adjacent lane having a snow covering. Consideration may need to be given to the effect that movement of wind may have on snow which is falling on lanes not covered by the structures or which has fallen causing drifting under the canopy. A further operational issue will surround the manner in which snow that is ploughed to the left hand side may exert forces on the lower sections of the structures if the amount involved is significant. Additionally, methods to potentially remove this snow, as (if screened from the winter sun by the structure) it may not readily melt on its own accord, will need to be considered also.

13.15 LIGHTING

The impact of constructing any of the structures could have a detrimental impact on the current light levels on the carriageway. Further study would be necessary to determine if and where artificial lighting may be required given the construction of the canopy. Emergency lighting may also be necessary to direct people to emergency exits in the event of an emergency; this too needs further consideration at the next stage of design.

13.16 USE OF PILED FOUNDATIONS

As per Chapter 5: Geotechnical Constraints, it is proposed that the foundations will be constructed using the piled foundation method on the basis of a minimum plan footprint. During construction consideration should be given by the contractor to noise, potential for flying debris, and proximity of piling to other structures which may cause ground movement/undermining.

14 DESIGN ACTIONS

14.1 INTRODUCTION

For the design of the structures the design actions (loadings) listed below have been considered. The structures have been checked at both Ultimate Limit State (to check adequate capacity exists against failure) and to Serviceability Limit State (to check the deflections of the structure are within agreed limits). The structural members are sized to ensure the criteria of Ultimate Limit State and Serviceability Limit State are met.

Ultimate Limit State and Serviceability Limit State combinations of the design actions have been determined in accordance with BS EN 1990.

The designs also take cognisance of the effects of fatigue on the structures due to the applied variable actions and possible load reversals e.g. dead load plus snow loading versus uplift from wind action.

14.2 WIND LOADS

Wind loads have been calculated in accordance with BS EN 1991-1-4:2005 and the UK National Annex. When calculating wind loads there are a number of values given that are based on the location of the structure. Assumptions have been made for all these values and are listed below with their justification:

- Directional factor (c_{dir}) = 1.0 (This is taken conservatively.)
- Fundamental basic wind velocity ($v_{b,map}$) = 23m/s (This wind speed is conservative for most of the cities, town and motorways in England.)
- Altitude (A) = 100 metres (This number was estimated at by looking at a looking at the altitude of different cities across England.)

14.3 SNOW LOADS

Snow loads have been calculated in accordance with BS EN 1991-1-3:2003 and the UK National Annex. When calculating snow loads there are a number of values given that are based on the location of the structure. Assumptions have been made for all these values and are listed below with their justification:

- Snow load Zone Number = 3 (This value is obtained from Figure NA.1. Zone 3 cover most of England and is more onerous than Zones 1 and 2 which are found in south west England. Zone 4 exists in the Peak District and in north east England however as this is only a small section of the country it is thought that it would be overly conservative to use Zone Number 4.)
- Altitude (A) = 100 metres (This number was estimated by looking at a looking at the altitude of different cities across England.)

14.4 CLADDING

For the purposes of this study the total load of the cladding, purlins, and connections has been assumed to be 1kN/m^2. This is considered to be a slightly conservative for all of the timber, metal sheeting, Perspex and glass cladding types considered.

14.5 IMPACT LOADS

It has been assumed that the walls of the canopy can be adequately protected by a Road Restraint System (RRS) installed within the verge and that sufficient vertical clearance is provided from the road surface avoid vehicle collision. As such impact loads have not been considered in the design.

14.6 VENTILATION LOADS

For the fully enclosed canopy (Structure No. 3), ventilation fans will be required as the tunnel may be too long to self-ventilate to prevent the pollutants inside the tunnel exceeding regulations levels and also for ventilation during a fire as discussed in Chapter 9. Through discussions with tunnel ventilations engineers at WSP|PB and looking at examples of ventilation systems in tunnels, we propose the following assumptions to be used in the design.

- Number of fans required across canopy = 4 spaced equally underneath the canopy
- Load of each fan = 12.5kN
- Fan Diameter = 1.25 metres
- Fan spacing along canopy = approx. 100m

Although this appears to be reasonable to us, it should be noted that no ventilations analysis of design have been undertaken and that the ventilation requirements are likely to vary significantly between different situations depending on the length of the tunnel, geometry and traffic conditions.

For the partially enclosed canopy option (Structure No. 2), it is assumed that the open section in the middle of the canopy provides adequate ventilation for pollution level underneath the canopy to stay within the regulations levels. It should be noted however that even though it is thought that the open section will greatly improve the air quality underneath the canopy we have not carried out any analysis to say whether or not the opening width shown in the design is large enough to eliminate the need for mechanical ventilation.

14.7 MAINTENANCE LOADS

Maintenance loads have been taken from Table NA.7 from the UK National Annex to BS EN 1991-1-1:2002 for imposed loads on roofs not accessible except for normal maintenance and repair. The roof slope on all structures is less than 30° so the design loading considered was 0.6kN/m^2 UDL or a 0.9kN point load.

15 DEFLECTION CRITERIA

For the visual comfort of the vehicle drivers on the SRN it is important that the structures deflections are check under the persistent SLS situation (the situation experienced by the structure most of the time) to ensure they are not visible. Deflection limits have been determined from Tables NA.2 and NA.3 of the National Annex to BS EN 1993-1-1:2005 and are listed below:

Columns = Height/300 horizontally at top of column

Portal frame roof beam = Span/200 vertically taken at the mid-point of the beam

Cantilever = Length/180 vertically taken at the end of the cantilever

16 STRUCTURE NO. 1: A VERTICAL BARRIER WITH AN INCLINED SECTION OVER THE CARRIAGEWAY

16.1 DESIGN DEVELOPMENT

The optimum proposal for this structural solution would be for the inclined section to extend as far as possible over the carriageway. As a starting point, the inclined roof section was considered to extend over the verge (2.5m), hard shoulder (3.3m) and Lane 1 (3.65m). This equated to a 9.45m long roof section, cantilevered from the column as shown below in Figure 3.

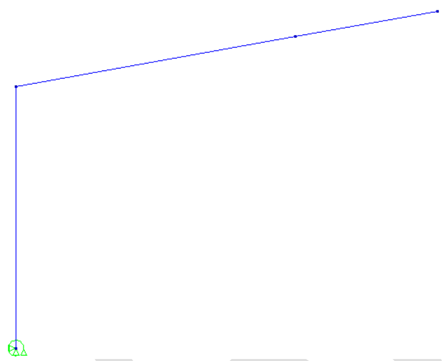


Figure 3: 9.45 m cantilevered canopy

During modelling, it became clear that deflections at the end of the roof section were critical in the design. The member sizes were increased to reduce deflection but the result was the sections became only marginally utilised in capacity and were therefore considered inefficient.

Consideration was also given to the addition of a stay to the rear of the canopy, which would certainly aid in deflection control and in being able to reduce the column size. This arrangement is presented below in Figure 4, however, is discounted from further consideration due to the additional land take requirement to site the stay.

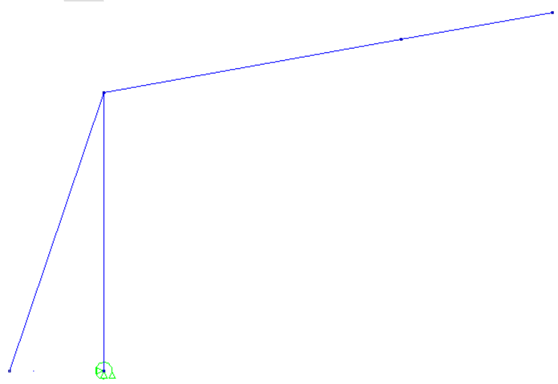


Figure 4: 9.45 m cantilevered canopy with stay

An alternative to the stay was the introduction of a tie, as illustrated below, in an attempt to reduce the deflection of the roof:

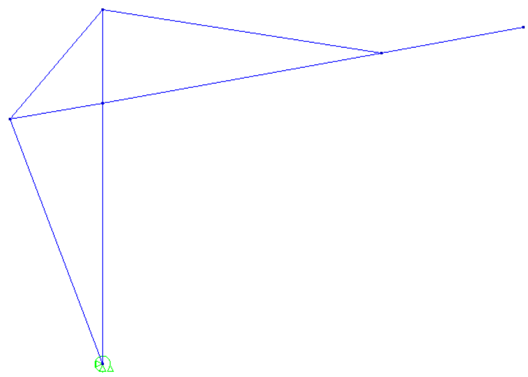


Figure 5: 9.45 m cantilevered canopy with tie

Although the tie helped reduce deflections, they still remained critical in the design and it was difficult to meet deflection criteria (refer to Chapter 15: *Deflection Criteria*) with any efficiency of the members. Due to the poor utilisation of the members and the difficulty in achieving acceptable deflections, along with the potential land take requirement problems to facilitate the tie to the rear of the columns, it was decided not to pursue this length of cantilever/roof further.

The design was then modified to reduce the roof length and remove the tie section to the rear of the canopy, thus addressing the issue of increased land take requirement. The roof length was reduced to 5.8m to cover the verge and hard shoulder only to address member utilisations:

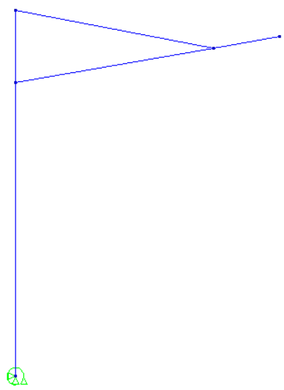


Figure 6: 5.8 m cantilevered canopy with strut/tie

It was possible to design the above canopy with members at efficient utilisation (circa 80%) for the given load cases whilst meeting the deflection criteria given in Chapter 15: *Deflection Criteria*.

16.2 PROPOSED DESIGN

The proposed design for *Structure 1: A vertical barrier with inclined roof section* is shown in Appendix A, sketch number 621105247-SKT-001. The canopy will consist of a “frame” formed from an upright column and a pitched roof section formed from beams.

It is proposed that each “frame” is formed from a 356x406x467 UKC (column) extending to a height of 7.3 metres above the carriageway level. The size of the column could be slightly amended where the road on the SRN is in cutting (the column will therefore be shorter) or where the road is on embankment (the column will therefore need to be longer).

A 5.8 metre long roof section would be cantilevered off the column at a height of 5.7 metres above carriageway level to provide the required headroom clearance. A Circular Hollow Section (CHS) is proposed, connecting at a point ¾ along the length of the roof section to the tip of the column to aid in deflection control. A steel section is proposed rather than a cable as this member is subject to both tension and compression, dependant on the various wind load cases considered.

It is proposed that the “frames” are at 8 metre centres and that purlins span between the “frames”. A purlin such as a 262 Z 20 sleeved purlin would likely be suitable to withstand the actions considered (refer to Chapter 14: Actions) for the roof section and a span of 8 metres, whereas a 232 C 16 sleeved purlin (cladding rail) would likely be suitable for the wall sections of the structures.

It is proposed that the cladding systems span between purlins which in turn span between “frames”.

16.3 FOUNDATION DESIGN

Adopting the assumed ground conditions and soil parameters detailed in Chapter 5: Geotechnical Constraints, an outline foundation design has been determined based on support reactions extracted from a structural model. The foundation design shall be a single 3.no. 750 millimetre diameter, 9 metre long pile under each column extending. The piles will be spaced along the length of the road at 1.5 metres centres. A pile cap 4 metres long, 1 metre wide and 1.4 metres deep will connect the pile together.

17 STRUCTURE NO. 3: FULLY ENCLOSED STRUCTURE

17.1 DESIGN DEVELOPMENT

The structural form chosen for the fully enclosed canopy is a portal frame extending over the carriageway. The portal frames shall be equally spaced along the carriageway and will support purlins which span between portal frames. Cladding will span between purlins. Transverse stability is provided by the portal frames and longitudinal stability is provided by bracing between the portal frames. This system is versatile, adaptable and eliminates moments on foundations allowing them to be smaller and the column bases are modelled as pinned. This is a common structural form used in large warehouses and on other structures investigated as part of this study.

Adopting the indicative road geometry defined in Chapter 4, the total distance between the inside faces of the walls of the canopy is 38.1 metres. Initially installing a mid-span support in the central reserve was considered, however, this was discounted for the reasons below:

- Installing columns into the central reserve could reduce existing sight lines on curved roads and may not be able to be applied to typical locations across England.
- Installation of the columns and foundation in the central reserve would require one or more lane closures during construction which is undesirable on heavily trafficked SRN routes where a solution like this may be applied.

Typically, frame spacing's of between 1/4 to 1/5 of the span of the portal frame are found to be the most efficient in the design of structures of this type. The total span of portal frame without a mid-span support is 38.1 metres. Considering this, and the size and spacing of the purlins that would be required for various spans, a frame spacing of 8 metres was chosen.

To allow for adequate drainage of the structure, it was determined at that a duo pitched roof with a nominal fall would be required. When investigating the effects of wind and snow actions, it was determined that there was an advantage in keeping the roof relatively flat and low as it reduced the wind loads whilst having no effect on snow loads (this was because the pitch angle needs to exceed 30° before any reduction in snow load can be applied). Keeping the roof relatively flat also reduces the size of the structure which in turn reduces its visual impact. It also makes maintenance on top on the structure easier and safer. Only a nominal fall is therefore being provided on the roof on the canopy.

Two types of framing systems were considered for this design; a portal frame where the roof supporting element comprises a truss, and a portal frame with the roof supporting element comprise single beams. Diagrams of each structure form are shown in Figure 6 and Figure 7.

Different types of trusses were considered for the portal frame with a truss roof member. Pratt and Warren trusses are typically economic for spans up to 50 metres with span to depth ratios of between 15 and 25. No other truss systems are economic at a span of 38.1 metres. A Pratt truss was chosen as the designer believes that the form made putting a nominal fall on the top chord of the truss simpler. However it should be noted that it is not expected that there would be any significant difference in economy between the two truss systems.

The depth of the truss was looked at with different arrangements analysed to determine the most economical. The resulting truss design has 1.6 metres between chord centrelines at frame columns and 2.4 metres between chord centrelines at the mid span. This give span to depth rations of approx. 24 at the columns and 16 at the mid span. Hollow sections have been chosen for the truss member as they are good in compression and have a neat appearance.

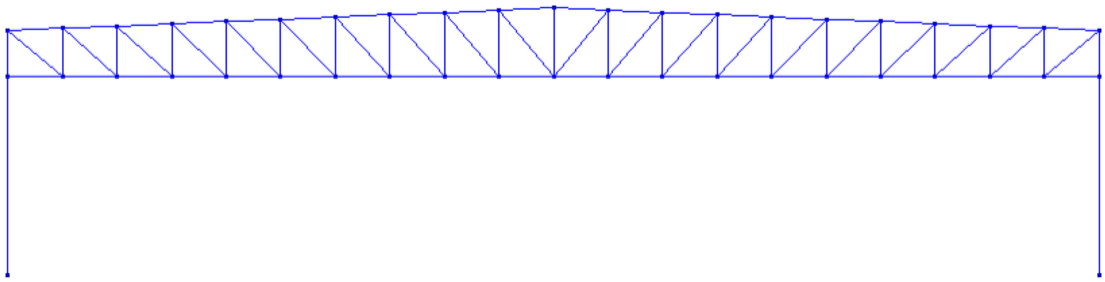


Figure 7: A portal frame where the roof supporting element comprise a truss

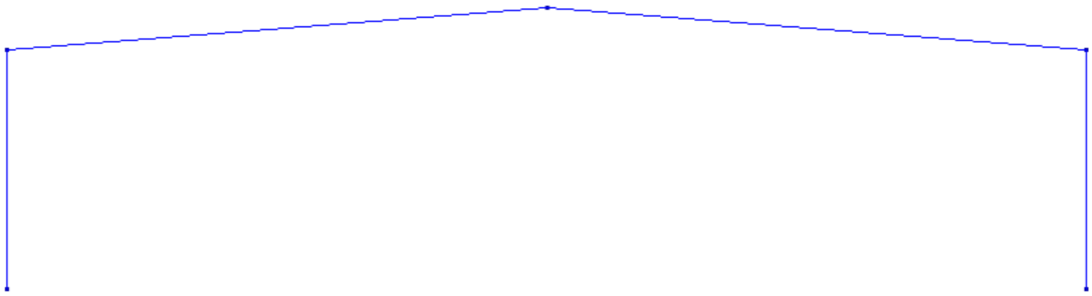


Figure 8: A portal frame with the roof supporting element comprise single beams

The other option considered was a portal frame with the roof elements being single beams. It was thought at first that an UKB would be appropriate; however, it was found that there was no standard beam where deflections were within a reasonable limit under dead load. A large component of the dead load was the girder itself, therefore increasing the girder size also increased the loading and as such it was found that a UKB could not be used in this instance.

Cellular beams were then looked at as an alternative option as their production leads to lighter beams with increased bending stiffness. A tapered cellular beam which increased in depth at mid-span was found that had acceptable deflections; however, this beam was still very heavy and would need to be 1.6 metres deep at the mid span. Deflection on the columns was also significant due to the pitched roof pushing out the top of the columns as the roof member deflected. In order to make the beam work, restraint of the bottom flange would be required to increase the lateral torsional buckling strength. This restraint could possibly require larger purlins and/or an additional beam spanning between the bottom flanges of the frames. In addition to the above design, the cost associated with manufacturing cellular beams is high. They are also not typically used in portal frames and for such long spans. When the truss portal frame design was produced, it was found that this frame option had approximately 25% more steel that the truss option discussed above. For these reasons, the structural form illustrated in Figure 7 is not considered the most economical solution and has not been proposed.

17.2 PROPOSED DESIGN

The proposed design for *Structure 3: Fully enclosed structure* is shown in Appendix A, sketch number 62102547-SKT-003.

The proposed design is a portal frame with the truss roof member as discussed in the previous section. This truss comprises of 160x160x12 SHS for the top and bottom chords and 160x80x6.3 RHS for the bracing members. Connections between the chords and bracing members are proposed to be full penetration butt welds. For ease of transport and to site and manufacturing, the truss can be prefabricated in three sections which can then be bolted together on site before being lifted into place.

The columns for the frame are proposed as 356x368x202 UKC. The connections to the truss will be bolted. The column connection to the pile is to be a bolted base plate connection designed to behave like a pin.

The frames are at 8 metre centres with purlins spanning between them which support the cladding. A 262 Z 20 sleeved purlin system on the supporting the roof cladding and a 232 C 16 sleeved purlin (cladding rail) system supporting the wall cladding would is suitable to withstand the actions considered (refer to Chapter 14: Actions) and the span of 8 metres.

Transverse stability of the structure is achieved by the portals frames while longitudinal stability is achieved by cross bracing between frames. It is proposed that the steel flat cross bracing be provided on the two end bays and every fifth internal bay of the structure.

Each ventilation fan will be supported off two 150x90x24 PFC'c connected between two frames. The ventilation frames will hang within the depth of the truss, which it is assumed does not substantially affect their effectiveness.

17.3 FOUNDATION DESIGN

Adopting the assumed ground conditions and soil parameters detailed in Chapter 5: Geotechnical Constraints, an outline foundation design has been determined based on support reactions extracted from a structural model. The foundation design shall be a single 750 millimetres diameter, 9 metres long pile under each column extending. No pile cap will be required.

18 STRUCTURE NO. 2: PARTIALLY ENCLOSED STRUCTURE

18.1 DESIGN DEVELOPMENT

Before developing the above designs for Structure 1 and Structure 3, the structural form that Structure 2 should take was not clear. The design proposed in the first draft of the end of commission report suggested that the roof could cantilever out from the columns, with stays tied back into the ground outside of the structure where the structure was placed on both sides on the motorway and a strut could be placed between the two cantilevers to improve stability.

When defining the road geometry that will be used, it became clear that there may be little space adjacent to the road and as such the use of stays is not appropriate for a typical situation. During the design development of Structure 1 it became clear that a cantilevered solution extending over the verge, shoulder and then any of the lanes was going to be simply uneconomic and although a strut was initially suggested, with a very large gap between the cantilevers a strut just adds weight to the structure with little benefit to its strength and stability.

For the above reason, it was decided that the cantilevered option was not appropriate and a portal frame structure extending over the entire motorway is the only option given further consideration. The partial opening is achieved by not installing cladding over the middle section. The design development process for Structure 3 concluded that a truss option with a depth of 1.6 metres at the columns and 2.4 metres mid span was the most economical and so the same geometry has been kept for this solution. As a section the middle of the roof is not clad, actions on the frame are obviously smaller than those for Structure 3 and as such section sizes have been reduced.

The open section of roof has been chosen to extend over the central 11.8 metres of the motorway. This leaves the cladding covering the verge, hard shoulder and Lanes 1 and 2 on a typical three lane motorway. The purpose of leaving a gap is to reduce the load the structure carries and to increase ventilation to eliminate the need to install expensive mechanical ventilation equipment. There is no guidance as to how large a gap is required to eliminate the need for mechanical ventilation and no analysis has been undertaken to determine what would be necessary. The size of the opening has been chosen by the designer as something that appears reasonable, based around highway cross section geometry.

18.2 PROPOSED DESIGN

The proposed design for *Structure 2: Partially enclosed canopy* is shown in Appendix A, sketch number 62105247-SKT-002.

The proposed design is the portal frame with the truss roof member discussed in the previous section. This truss comprises of 120x120x10 SHS for the top and bottom chords and 120x60x5 RHS for the bracing members. Connections between the chords and bracing members are proposed to be full penetration butt welds. For ease of transport, the truss can be prefabricated in three sections which can then be bolted together on site before being lifted into place.

The columns for the frame are proposed as 356x368x153 UKC. The connections to the truss will be bolted. The column connection to the pile is to be a bolted base plate connection designed to behave like a pin.

The frames are at 8 metre centres with purlins spanning between them which support the cladding. A 262 Z 20 sleeved purlin system supporting the roof cladding and a 232 C 16 sleeved purlin system supporting the wall cladding would is suitable to withstand the actions considered (refer to Chapter 14: Actions) and the span of 8 metres.

Transverse stability of the structure is achieved by the portal frames while longitudinal stability is achieved by cross bracing between frames. It is proposed that steel flat cross bracing be provided on the two end bays and every fifth internal bay of the structure.

18.3 FOUNDATION DESIGN

Adopting the assumed ground conditions and soil parameters detailed in Chapter 5: Geotechnical Constraints, an outline foundation design has been determined based on support reactions extracted from a structural model. The foundation design shall be a single 750 millimetres diameter, 6 metres long pile under each column extending. No pile cap will be required.

19 COST ESTIMATE

Cost estimates for Structure 1, 2 and 3 for a nominal 1 km length have been calculated by our in-house team of quantity surveyors (QS's). Our QS's are familiar with the Highways England cost estimating process through their on-going commissions under PSF Lot 3 including Commercial Auditing on live projects, our inclusion on the SPaTS framework, etc.

The cost estimates for each of the options are indicated below. These estimates are for the structures presented in the Appendix A drawings where timber cladding is adopted for the walls and Perspex/GRP is used for the roof sections. These estimates presented below are considered as the "base cost" and are given in association with the key assumptions and exclusions:

Structure 1: £21.7 million per km

Structure 2: £31.1 million per km

Structure 3: £46.2 million per km

A detailed breakdown of the cost estimates are include in Appendix B and Structure 1 assumes that independent provision is made on both sides of the carriageway.

19.1 ASSUMPTIONS:

A number of assumptions have had to be made in the compilation of the cost such as:

- The scheme is priced as a stand-alone scheme although it is envisaged that the scheme will be built alongside an All lane running (ALR) scheme. So certain time related charges have been allocated to the ALR scheme and are not included in the cost estimates.
- The prices are based on competitively tendered rates.
- The scope of work to any utilities diversions is unknown at this time and has been assumed.
- To enable this estimate to be comparable with the Cut and Cover bench mark estimate prices have been kept at Q3 2015 levels
- It is assumed any upgrade works to the carriageway has been excluded.
- It has been assumed this forms part of an ALR scheme and as such items such as traffic management, road space booking and breakdown facilities will be only be borne by this scheme if they exceed the requirement for the ALR scheme.
- An Optimism bias of 44% has been allowed, this is the maximum allowable as recommended by the Green Book as published by the OGC.
- The estimate is based on historical unit costs of similar schemes and adjusted as necessary to the design brief provided.
- Note that metal cladding is assumed to be single skin PVF2 coated aluminium profile sheeting. Without insulation or inner skin. No openings for ventilation or windows.
- Glass walls will be single glazed units on sub frames.
- Perspex is Fybagard GRP fire rated from Smyth Composites.
- Timber cladding is Jakoustic Plus fencing from Jacksons Fencing.
- Concrete walling is to be fair faced finish no other decorative feature to inside or outside face (such as brick or stone facing).

19.2 EXCLUSIONS

The following are excluded at this time:

- Value Added Tax
- Extra over inflation as a result of other major civil engineering schemes causing the market to overheat.
- Highways England's internal costs.
- Works which may be requested by Highways England to be carried out at the same time as the construction to minimise disruption to road users.
- Maintenance Costs – see separate item below on this matter.
- Land costs, land take and compensation to land owners, legal and surveying fees associated with land purchase and compensation.
- Inflation past Q3 2015.
- Planning application costs.
- Disposal of hazardous material e.g. asbestos, VOC, costs associated with environmental and ecological.

19.3 ADDITIONAL COST INFORMATION

Additional work has been carried out in regard to different combinations of cladding materials for each of the structures assessed above; refer to Appendix B for further details. The costs presented in Appendix B take into account the cost of the different cladding materials and an allowance for the increase (if required) from the base case design in the steel tonnages needed to support that material made. The range of costs from Appendix B for the various combinations of wall and roof combinations is

- £13.3 to £38.3 million per kilometre in the case of Structure 1, with provision on both sides of the carriageway;
- £14.7 to £46.9 million per kilometre in the case of Structure 2; and
- £23.2 to £71.6 million per kilometre in the case of Structure 3.

From work undertaken previously by WSP|PB and reported in the End of Commission Report, a range of costs for proposals prepared by the Ministry of Infrastructure and the Environment in the Netherlands (Rijkswaterstaat) have been correlated to 2015 prices and are included below in Table 5. There are, however, strong concerns over the validity of these Dutch figures on the basis of potential exclusions and omission of critical items.

Additional sources of information relevant to Structure 3 have been obtained for the A3 Hindhead schemes, from Treasury publications and work which WSP|PB have done for the provision of a concrete enclosing structure around existing live infrastructure. The associated range is included for reference in Table 5 also under the fully enclosed canopy/estimated costs from case studies cell. The costs are assumed to be construction related and do not include operations, maintenance or demolition costs.

With reference to the potential use of fabric materials as a roof covering as discussed in Section 11.3 above, information received from ClearSpan (taking into account their exclusion, exchange rates, etc) would suggest that the cost would be very comparable with the EDFE pricing provided in Appendix B. However, reductions could be expected in line with comments made in Section 11.3.

STRUCTURE TYPE	ESTIMATED COST FROM CASE STUDIES	ESTIMATED COST OF WSP|PB CONCEPT DESIGNS
Cantilever Barrier	£5 million to £13 million per kilometre (on one side of the road)	£6.7 million to £19.2 million per kilometre (on one side of the road)
Partially Enclosed Canopy	No structure studied is directly comparable to estimate a cost however it is expected that a significant saving can be made over the fully enclosed canopy.	£14.7 to £46.9 million per kilometre
Fully Enclosed Canopy	£9 million to £185 million per kilometre	£23.2 to £71.6 million per kilometre

Table 5: Cost estimates from various sources for structure similar to Structure 1, 2 and 3

19.4 MAINTENANCE AND DEMOLITION COSTS

For the three base case structures, Structure 1, 2 and 3 with timber walls and Perspex roof, an estimate has been established for the maintenance and demolition cost (to ground level leaving the foundations in place). The differences across the material options discussed elsewhere are not deemed sufficiently significant to address each one individually under this heading. A key assumption is that the work is carried out at the same time as other planned activities on the SRN. With the short Design Life and the scrap value of the steel structures, costs as indicated in Table 6 below are calculated. An allowance has been made for the extra over maintenance required for the positive drainage system being utilised.

Structure	Maintenance for 15 year Design Life and demolition costs, £ per kilometre
1	£86,000
2	£175,000
3	£604,000

Table 6: Maintenance and demolition cost assessment for Structure 1, 2 and 3

19.5 SUMMARY REGARDING COSTS

From the cost estimation work carried out to date, the option of metal walls and metal roofing is cheaper than the other options investigated. However, in a number of cases this may not be the most appropriate solution to be implemented e.g. less natural light, visually intrusive, etc. As indicated elsewhere, the site specific influences must be taken into account in the selection of the materials to be used. The generalised preferred option after balance and compromise is chosen as the timber/Perspex combination presented as the base cases for the three structural options as presented in this report.

20 QUALITATIVE ASSESSMENT OF AIR QUALITY IMPROVEMENT

Three structures are proposed as follows:

- Structure 1: Cantilevered Barrier;
- Structure 2: Partially Enclosed Barrier; and
- Structure 3: Fully Enclosed Barrier;

Structure 1 will comprise a vertical structure of approximate height 5.7 m and a horizontal structure set at an angle of approximately 10° which will overhang the road corridor by a distance of 5.8 metres. Depending on the specific site conditions, the structure could be positioned on either one or both sides of the SRN road corridor.

Structure 2 would comprise a canopy with a gap in the cladding/roof of the structure above the centre of the road. At this time the exact dimensions of the gap has not been determined as it would depend on the cross section of the SRN being addressed, but for the purposes of this assessment it is assumed that the verge, hard shoulder and Lanes 1 and 2 of a typical D3M cross section of the road corridor would be covered i.e. significantly more than Structure 1.

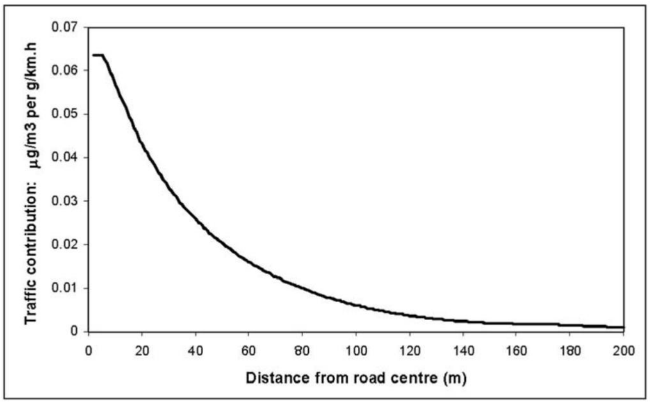
Structure 3 will effectively comprise fully enclosed canopy of approximate height 8.6 metres which will be used to enclose sections of the SRN. It is further understood that the design will include the provision of a ventilation system discharging at the portals but no specific method for removing the air from within the tunnel i.e. via a stack, etc is included at this time.

The effectiveness of such structures to improve the air quality at a specific receptor in the vicinity of the SRN is dependent on a number of factors, namely the proximity and relative elevation of the receptor to the source; the horizontal extent and vertical height of the proposed barrier and the prevailing wind direction.

In the absence of any modelling work, the assessment of the effectiveness of the structure to reduce the air pollution at a receptor is based on a qualitative review of the design and the experience and knowledge of our specialist team.

It is considered that the proposed barriers will affect the dispersal of pollutants arising from the road traffic in a number of ways including increasing the distance that pollutants will need to travel between the source (road) and the receptors, disrupting the flow of wind across the carriageway and effectively raising the height of the release point.

As illustrated in Figure C1 within the Design Manual for Roads and Bridges (DMRB) Volume 11, Section 3, Part 1: Air Quality Annex C (provided overleaf for ease of reference), the contribution to pollutant concentrations arising from traffic drops off rapidly with distance from the road such that the most significant reduction in pollutant concentrations is experienced within 20m from the centre of the road.



Therefore any increase in the distance between the source and receptor is likely to have a significant effect on the concentrations experienced at receptors in close proximity to the road.

The effect of disrupting the wind flow is more complex and difficult to predict and the effect will be dependent on the wind direction. It is likely that as the source will effectively be raised off the ground that dispersion will be improved with greater dilution of the plume before it reaches the ground.

It is considered that Structure 3 will provide the most effective solution. However, it should be noted that there will be an increase in pollution concentrations at the tunnel entrance/exit points. Therefore care should be taken with the siting of tunnels such that the entrance/exit points are located away from sensitive receptors.

It is considered that there is very little difference between the likely effectiveness of Structure 1 and Structure 2 in reducing the air pollution effects of the road traffic emissions. It is considered likely that Structure 2 would be slightly more effective than Structure 1 due to the greater coverage and therefore the greater distance that pollution would need to travel from source to receptor. However, the effect of a greater concentration of pollutants emerging from the gap above the central reserve is difficult to predict.

Table 7 below presents a summary of the assumed air quality improvement at the receptor for the different structures considered.

Structure type			Effectiveness		Comments
-	Vertical barrier		L		Limited trials show that a vertical barrier can have little impact
1	Vertical barrier with inclined section		L		Anticipated to be only marginally more effective than a vertical barrier
2	Partially enclosed barrier		M/L		Effectiveness is dependant upon a number of factors including width of gap, length of canopy and local topography. Effectiveness cannot be predicted without modelling but is expected to be between that of structures 1 and 3
3	Fully enclosed barrier		H		Effective at containing air pollutants

Table 7: Possible Air Quality improvement levels

21 CONCLUSIONS

A feasible solution exists for the provision of Structure No. 1, 2 and 3, which can be advanced to mitigate the impacts of air dispersed pollutants from the SRN on adjacent receptors. Such provision will require the widening of verge provision to accommodate the structure at the rear of the verge area, allowing for drainage, Road Restraints Systems, drainage networks elements, communications cables and chambers, etc.

The structure solutions can be manufactured from a variety of materials, but it is recommended that Perspex or similar materials (in terms of weight, resistance to impact, see-through, etc) should be taken forward as the preferred option for the roofing material and that timber (in the form currently used for environmental barriers but with a greater level of air tightness) is utilised for the vertical wall components, linked to a steel frame structure.

The associated cost estimate for each structure has been determined as follows using this combination of materials i.e. timber for the vertical; wall component and Perspex for the roof section:

- Structure No. 1 (a vertical barrier with an inclined roof section): £21.7 million / km
- Structure No. 2 (a partially enclosed canopy): £31.1 million/ km
- Structure No. 3 (a fully enclosed canopy): £46.2 million/ km

It is noted that the costs for Structure 1 assumes that it is required on both sides of the carriageway. If not, the cost of provision on one side is thus recorded as being £10.9 million per km.

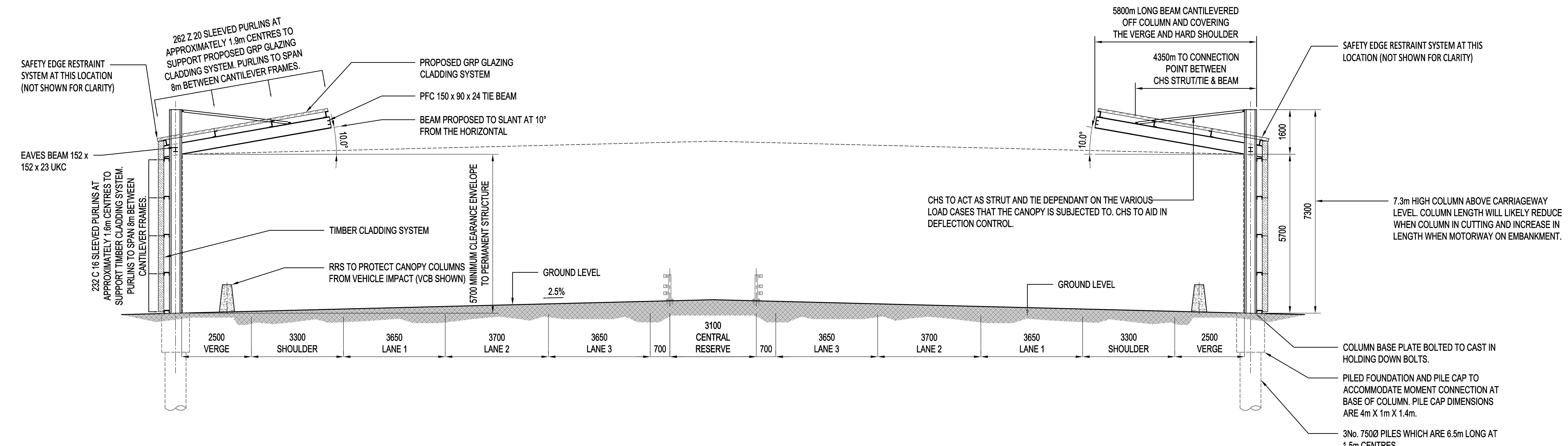
The costs above fall within the range of costs established for similar facilities by WSP|PB. It is stressed that the solution will be location specific but that on balance WSP|PB are minded that the combination of timber wall and Perspex roof provide the starting point for discussion.

In areas where visual impact is not an issue, a metal wall and metal roof option would provide the best economic solution.

If the issues associated with the use of fabric structures can be addressed, it may be worth investigating the option more thoroughly. Fabric covered structures offer the potential for a significantly cheaper alternative in certain circumstances if their shortcomings of the material can be addressed or accommodated.

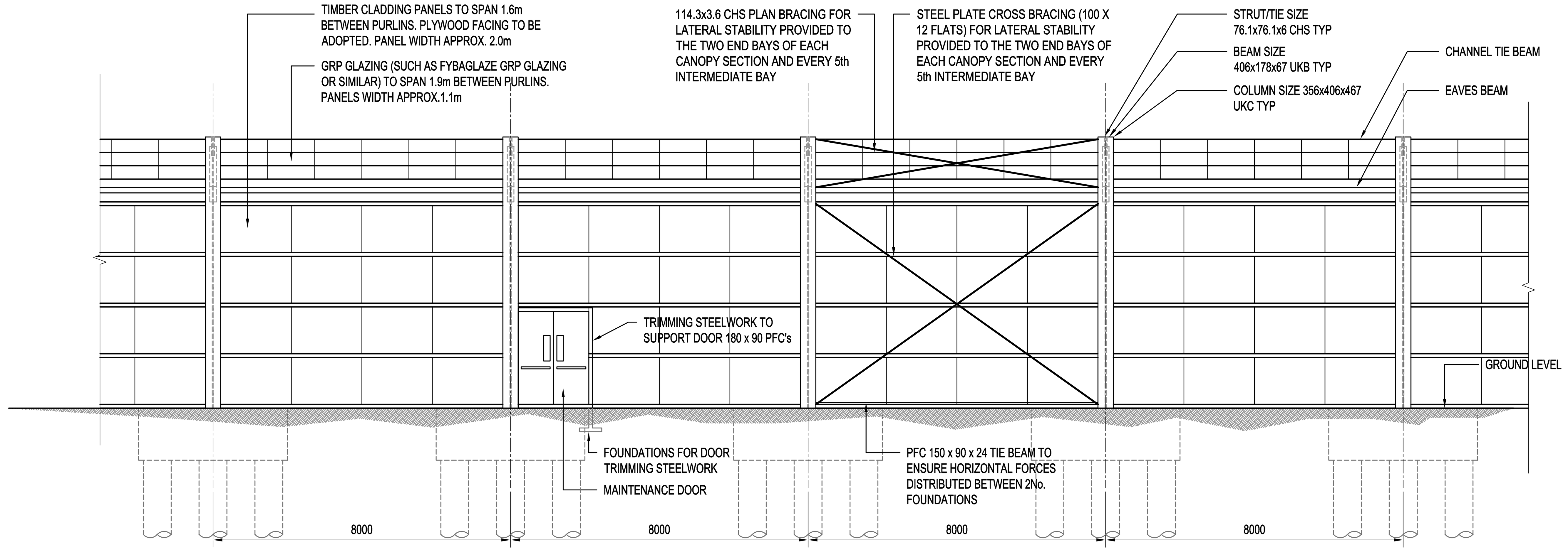
Appendix A

DRAWINGS



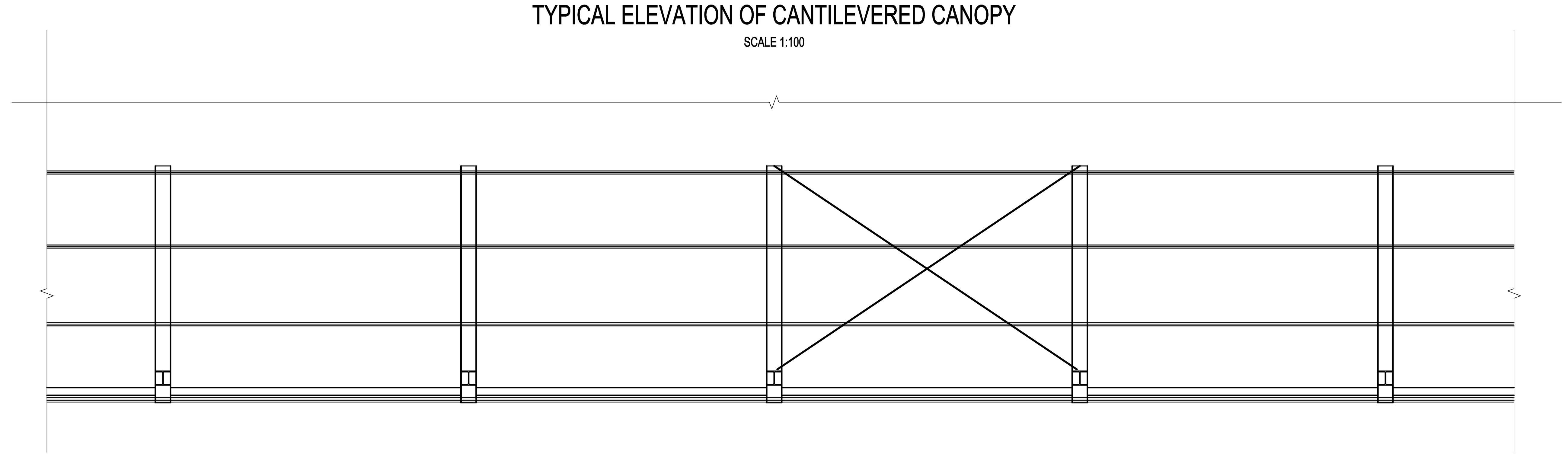
TYPICAL CROSS SECTION FOR 3 LANE MOTORWAY WITH CANTILEVERED CANOPY

SCALE 1:100



TYPICAL ELEVATION OF CANTILEVERED CANOPY

SCALE 1:100



TYPICAL PLAN OF CANTILEVERED CANOPY

SCALE 1:100

GENERAL NOTES:

1. ALL DIMENSIONS ARE IN MILLIMETRES UNLESS SHOWN OTHERWISE
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4. ALL MEMBER SIZES ARE BASED ON OUTLINE DESIGN ONLY FOR THE PURPOSE OF COST ESTIMATING. DETAILED DESIGN REQUIRED TO CONCLUDE ACTUAL DIMENSIONS.
5. OUTLINE DESIGN PRESENTED BASED ON ASSUMED PARAMETERS, SUCH AS GROUND CONDITIONS, ALTITUDE OF SITE AND LOCATION IN ENGLAND. DESIGN WILL REQUIRE MODIFICATION TO SUIT SPECIFIC SITES.
6. IT IS ASSUMED THAT THE CANOPY IS CONSIDERED AS "OPEN" AND THEREFORE A 15 MINUTE FIRE PROTECTION APPLIES, WHICH WILL BE PROVIDED BY THE STEELWORK ITSELF.
7. IT IS ASSUMED THAT THE STEELWORK WILL BE SUBJECT TO A C4 HIGH ATMOSPHERIC CORROSIVITY CATEGORY AND THAT THE CORROSION PROTECTION SYSTEM ADOPTED WILL BE A SHOP APPLIED PAINT SYSTEM ABLE TO ACHIEVE THE DESIGN LIFE OF THE STRUCTURE.
8. GRADE S275 STEEL PROPOSED ALONG WITH HOT STEEL ROLLED SECTIONS.
9. POSITIVE DRAINAGE SYSTEM IN FORM OF GUTTER (300x200mm TYP) AND DOWNPIPES (Ø200mm TYP) DISCHARGING TO EXISTING ROAD DRAINAGE SYSTEM.
10. MAINTENANCE ACCESS TO THE OUTSIDE SURFACES OF THE STRUCTURE WILL BE ACHIEVE VIA PERMANENT CAT LADDERS INSTALLED NEAR EACH EMERGENCY EXIT/MAINTENANCE ACCESS POINT. CAT LADDERS SHALL HAVE AN ANTI VANDAL SYSTEM IN ASSOCIATION WITH AN EDGE CONSTRAINT SYSTEM.
11. ADDITIONALLY, MAINTENANCE ACCESS TO THE ROADSIDE FACE OF WALLS ARE TO BE ACHIEVED BY TEMPORARY MEANS: LADDER, SCAFFOLD, MEWP ETC. LANE CLOSURE UNDER TEMPORARY TRAFFIC MANAGEMENT WILL BE REQUIRED DURING INSPECTION AND MAINTENANCE ACTIVITIES.

Rev	Date	Description	By	Chk	App
B	11-05-2016	NOTES ADDED	WJ	AC	RF
P01	18-04-2016	FIRST DRAFT	WJ	AC	RF

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AIR QUALITY CANOPY RESEARCH AND DEVELOPMENT

Title:
STRUCTURE 1 CANTILEVERED CANOPY

Drawn: W.JORDAN		Checked: A.CLARK	
Designed: S.MOIR		Approved: R.FINCH	
Date: 18/04/2016	Scale: AS SHOWN	A1	Sheet: -
Project Number: 62105247	Drawing Number: 62105247-SKT-001	Revision: B	

File Name: \\uk.wspgroup.com\central data\Projects\62105xxx\62105247 - CDF Canopy Study\Drawings\62105247-SKT-001-003.dwg

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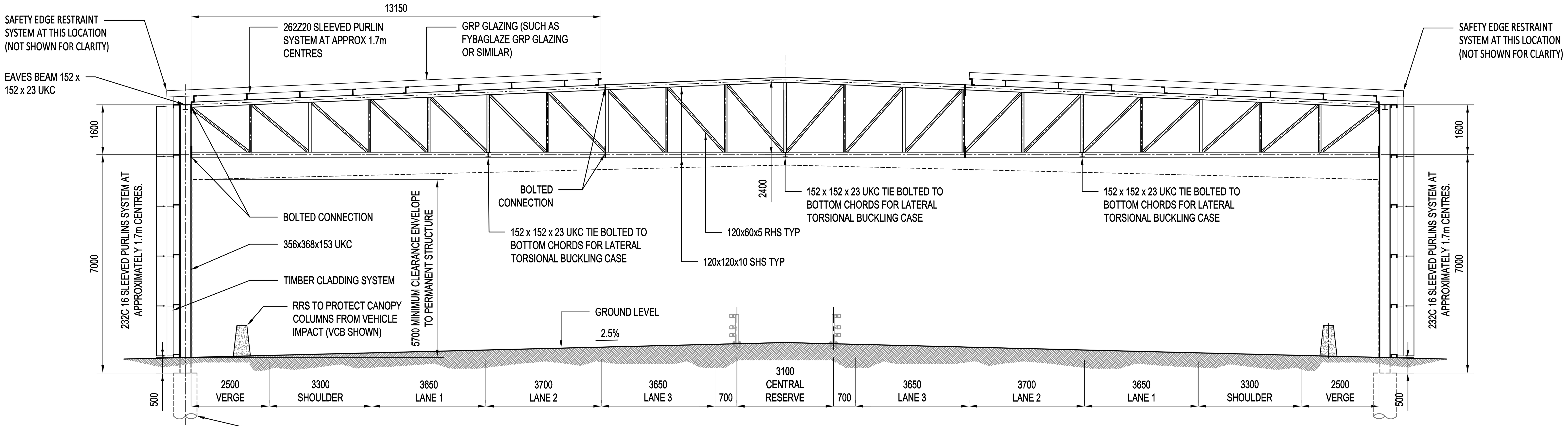
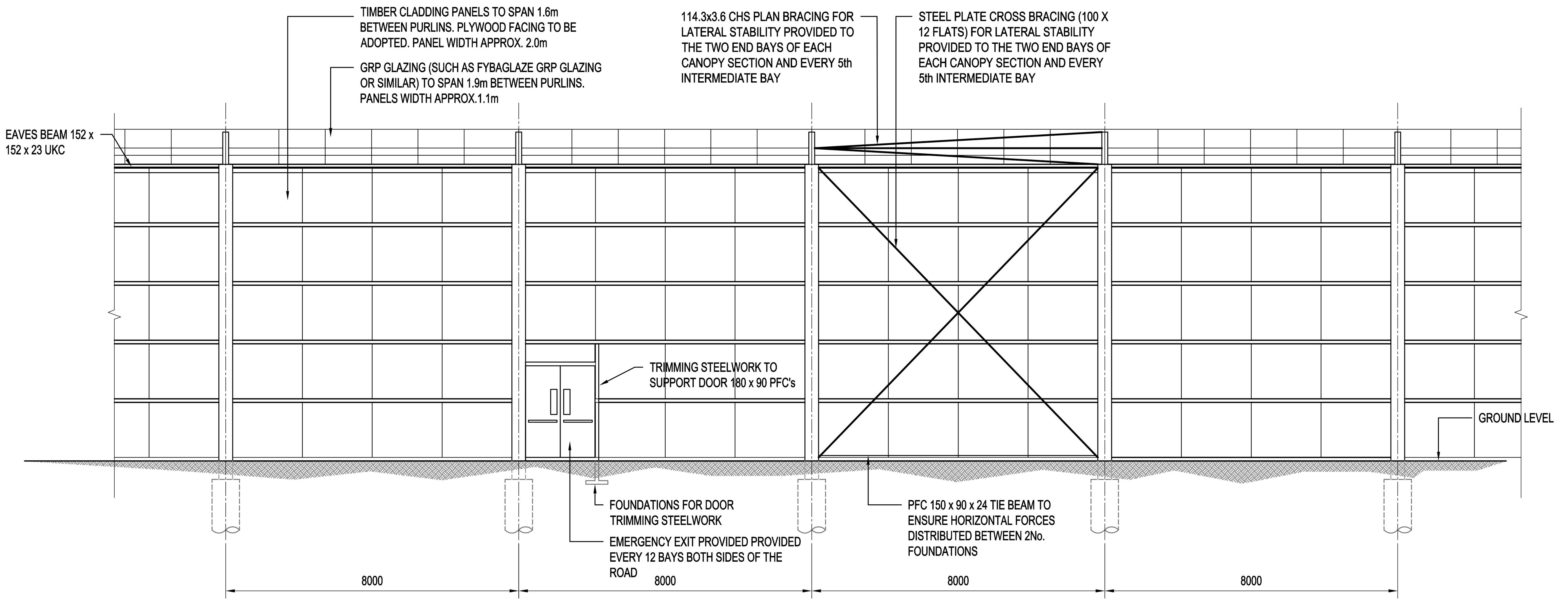
Plot Date: 11/05/2016 14:54:23



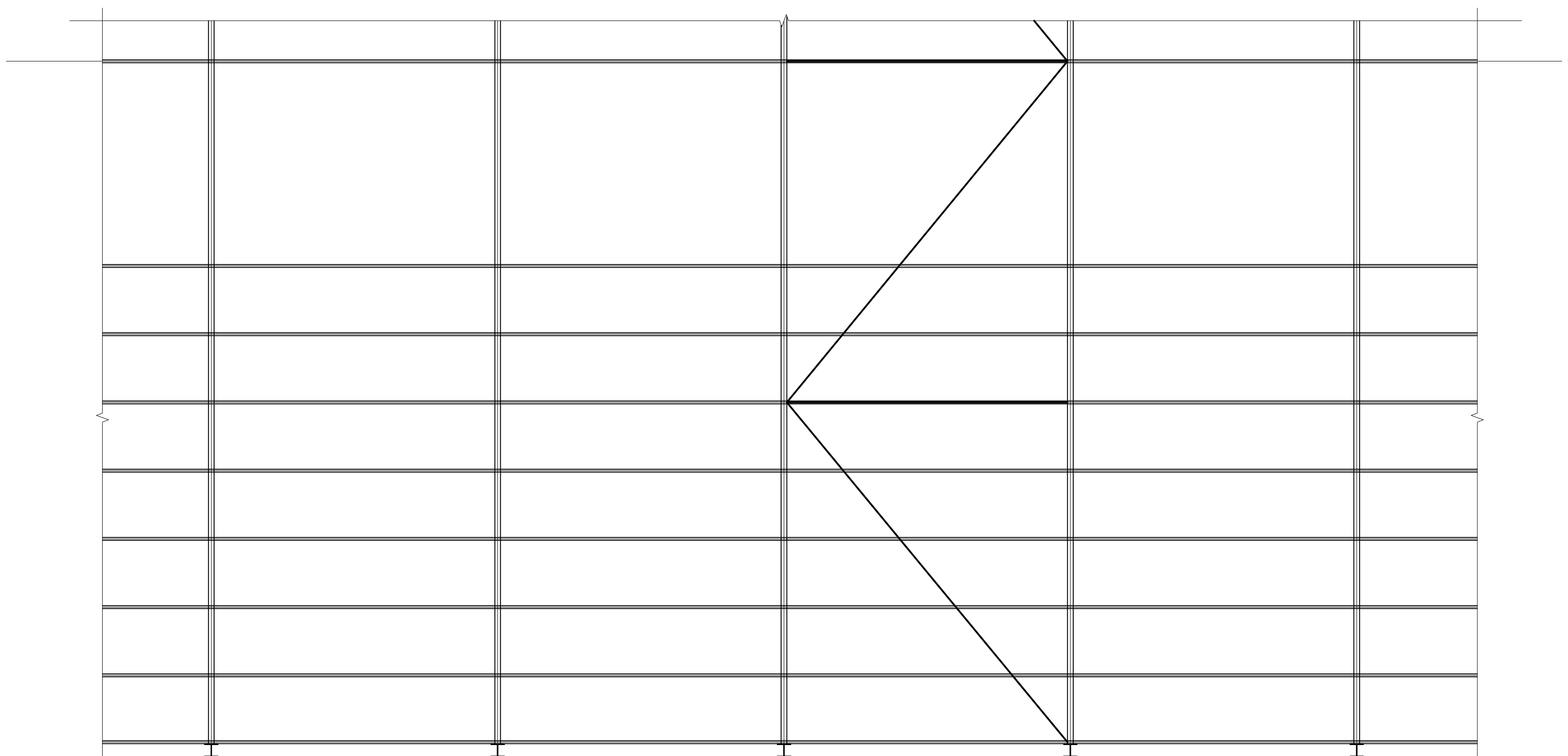
TYPICAL CROSS SECTION FOR 3 LANE MOTORWAY WITH PARTIALLY ENCLOSED CANOPY

SCALE 1:100



TYPICAL ELEVATION OF PARTIALLY ENCLOSED CANOPY

SCALE 1:100



TYPICAL PLAN OF PARTIALLY ENCLOSED CANOPY

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6. FIRE PROTECTION FOR STRUCTURE 2 AND 3 IS ASSUMED TO BE 60 min. FIRE PROTECTION TO BE ACHIEVED BY APPLICATION OF THICK FILM INTUMESCENT COATING
7. IT IS ASSUMED THAT THE STEELWORK WILL BE SUBJECTED TO A C4 HIGH ATMOSPHERIC CORROSIVITY CATEGORY AND THAT THE CORROSION PROTECTION SYSTEM WILL BE ACHIEVED THROUGH USE OF THICK FILM INUMESCENT COATING. THE INTUMESCENT COATING TO HAVE DUAL FUNCTION OF FIRE AND CORRISION PROTECTION.
8. GRADE S275 STEEL PROPOSED ALONG WITH HOT ROLLED SECTIONS.
9. POSITIVE DRAINAGE SYSTEM IN FORM OF GUTTER (300x200mm TYP) AND DOWNPIPES (Ø200mm TYP) DISCHARGING TO EXISTING ROAD DRAINAGE SYSTEM.
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Rev	Date	Description	By	Chk	App
B	11-05-2016	NOTES ADDED	WJ	AC	RF
P01	18-04-2016	FIRST DRAFT	WJ	AC	RF

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Title:
STRUCTURE 2 PARTIALLY ENCLOSED CANOPY

Drawn:	W.JORDAN	Checked:	A.CLARK
Designed:	B.MONAGHAN	Approved:	R.FINCH
Date:	18/04/2016	Scale: AS SHOWN A1	Sheet: -

Project Number:	Drawing Number:	Revision:
62105247	62105247-SKT-002	B

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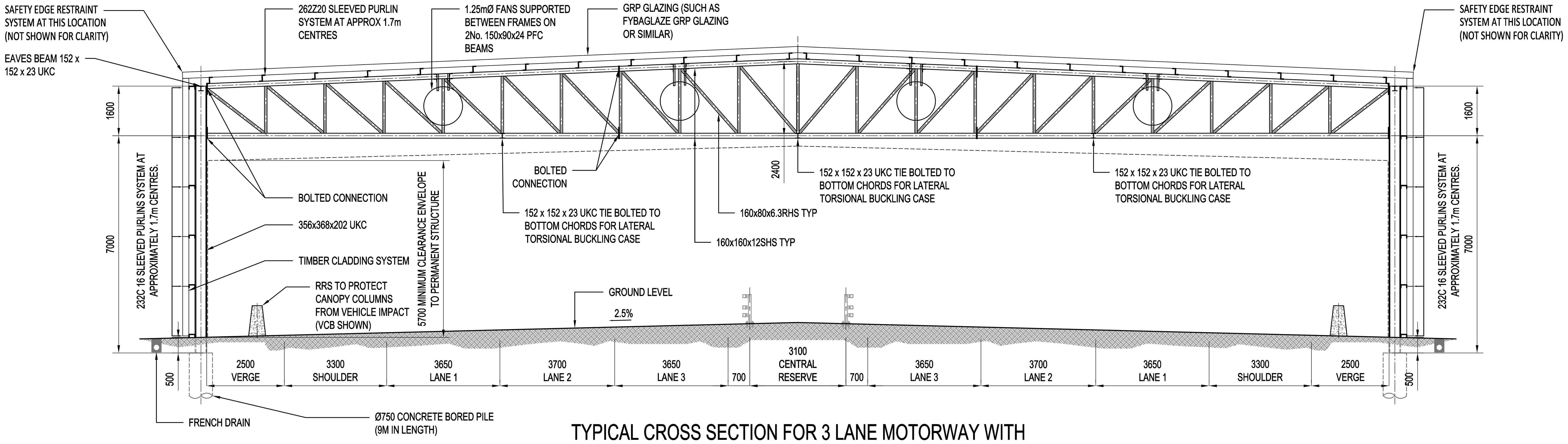
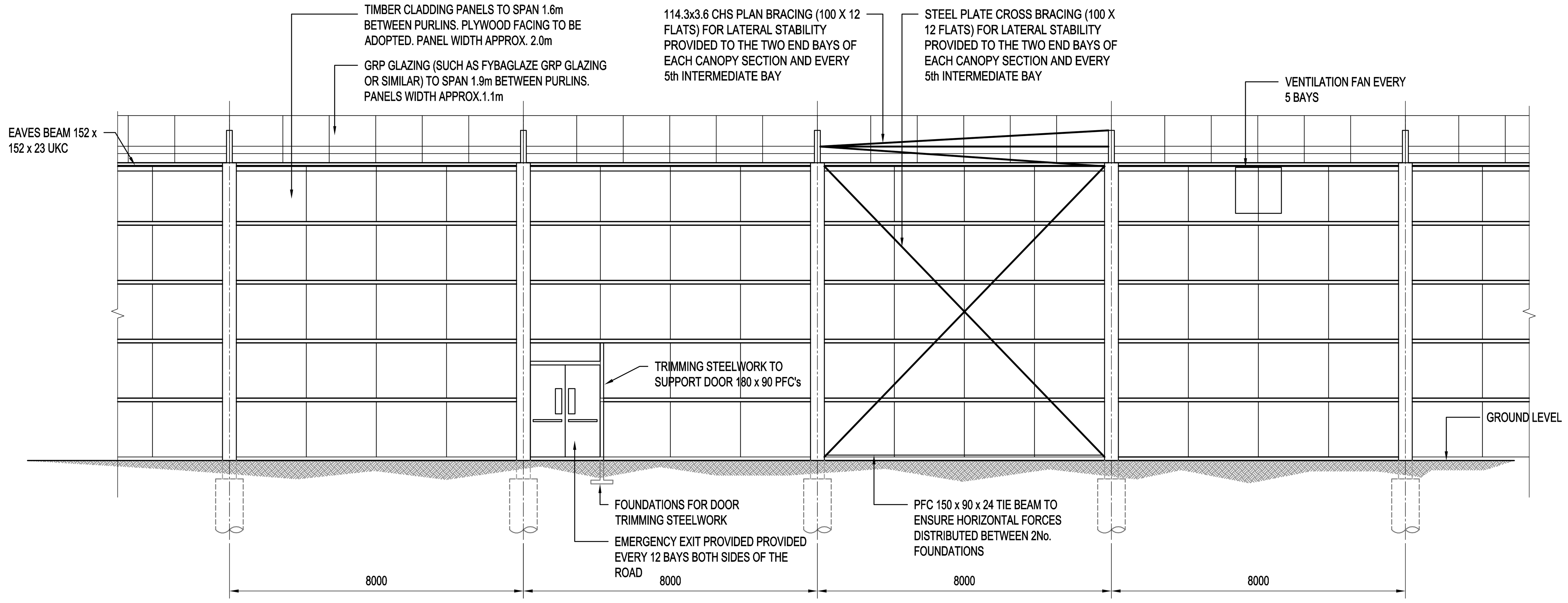


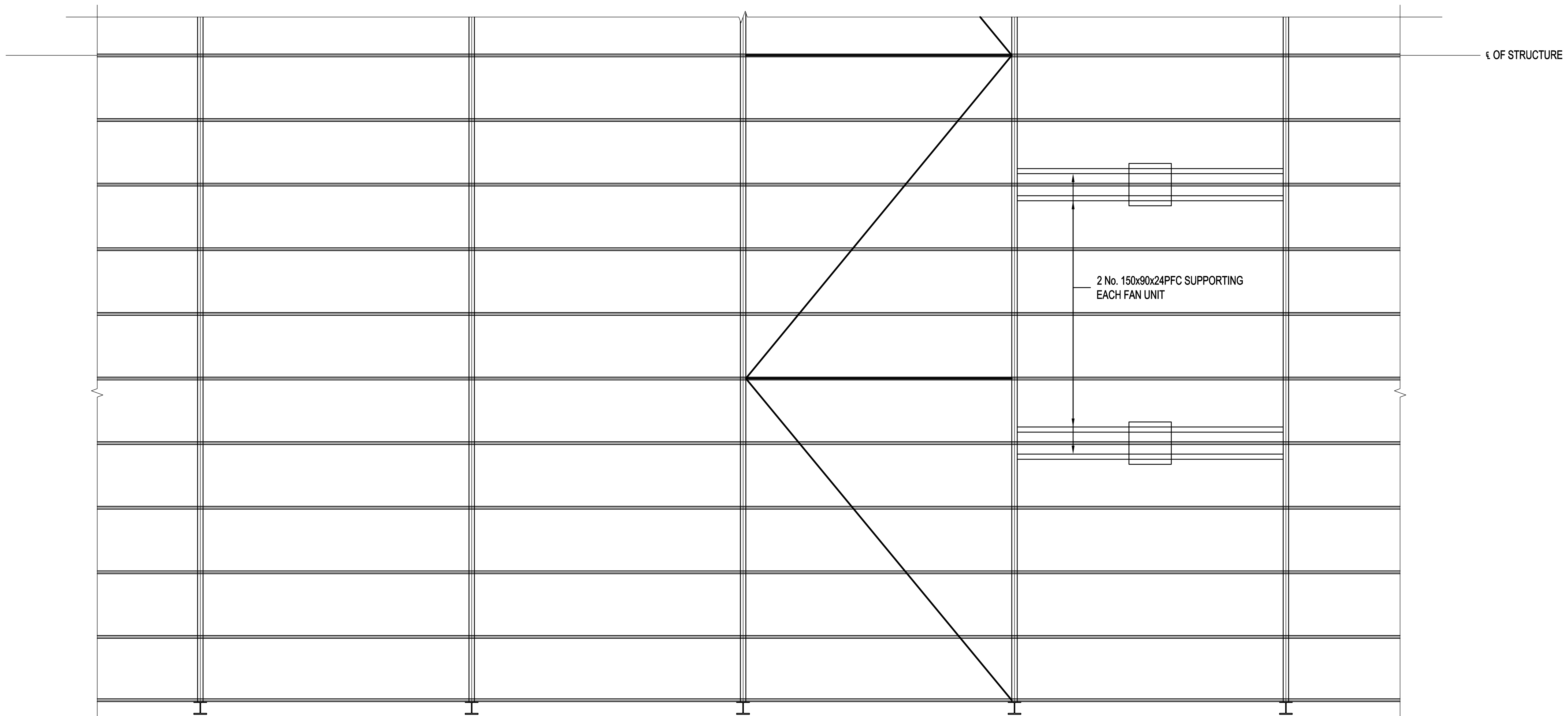
TYPICAL CROSS SECTION FOR 3 LANE MOTORWAY WITH FULLY ENCLOSED CANOPY

SCALE 1:100



TYPICAL ELEVATION OF FULLY ENCLOSED CANOPY

SCALE 1:100



TYPICAL PLAN OF FULLY ENCLOSED CANOPY

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11. MAINTENANCE ACCESS TO THE OUTSIDE SURFACES OF THE STRUCTURE WILL BE ACHIEVE VIA PERMANENT CAT LADDERS INSTALLED NEAR EACH EMERGENCY EXIT/MAINTENANCE ACCESS POINT. CAT LADDERS SHALL HAVE AN ANTI VANDAL SYSTEM IN ASSOCIATION WITH AN EDGE RESTRAINT SYSTEM.
12. A ROPED HORIZONTAL LIFE LINE SYSTEM SHALL BE PROVIDED ON TOP OF THE STRUCTURE FOR MAINTENANCE PERSONNEL TO CONNECT A SAFETY HARNESS TO FOR FALL PROTECTION.

Rev	Date	Description	By	Chk	App
B	11-05-2016	NOTES ADDED	WJ	AC	RF
P01	18-04-2016	FIRST DRAFT	WJ	AC	RF

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Title:
STRUCTURE 3
FULLY ENCLOSED CANOPY

Drawn: W.JORDAN		Checked: A.CLARK	
Designed: B.MONAGHAN		Approved: R.FINCH	
Date: 18/04/2016	Scale: AS SHOWN	A1	Sheet: -

Project Number:	Drawing Number:	Revision:
62105247	62105247-SKT-003	B

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Plot Date: 11/05/2016 14:55:32

Appendix B

COST ESTIMATE BREAKDOWN

Highways England

Summary
Air Quality Canopy
1000m Long

			Option 1 Cantilevered Canopy 1000m	%		Option 2 Partial Covered Canopy 1000m			Option 3 Fully Covered Canopy 1000m		
											Pricing Notes
	Design fees	**£**	**1,500,000**	12%	**£**	**2,150,000**	12%	**£**	**3,210,000**	12%	12% of construction cost
11.1	Construction stage site management fee	**£**	**750,000**	6%	**£**	**1,080,000**	6%	**£**	**1,600,000**	6%	6% of construction cost
11.3	**Total fees**	**£**	**2,250,000**		**£**	**3,230,000**		**£**	**4,810,000**		
	Construction Stage prelims	**£**	**3,470,000**	39%	**£**	**4,990,000**	39%	**£**	**7,430,000**	39%	38.5% of construction cost
	The Works										
	Series 200: Site Clearance	£	120,000		£	120,000		£	120,000		
	Series 300: Fencing	£	-		£	-		£	-		Part of ALR
	Series 400: Road Restraint Systems (Vehicle and Pedestrian)	£	-		£	-		£	-		Part of ALR
	Series 500: Drainage & Service Ducts	£	-		£	-		£	-		
	Series 600: Earthworks	£	-		£	-		£	-		Part of ALR
	Series 700: Pavements	£	-		£	-		£	-		Part of ALR
	Series 1100 : Kerbs, Footways and Paved Areas	£	-		£	-		£	-		Part of ALR
	Series 1200: Traffic Signs and Road Markings	£	100,000		£	250,000		£	250,000		
	Series 1300: Street Lighting	£	100,000		£	120,000		£	120,000		
	Series 1600: Piling and Retaining Walls	£	700,000		£	330,000		£	330,000		
	Series 1700: Structural Concrete	£	520,000		£	-		£	-		
	Series 1800: Steelwork for Structures	£	2,320,000		£	1,730,000		£	1,970,000		
	Series 1900: Protection for Steelwork	£	400,000		£	940,000		£	990,000		
	Series 2500: Cladding	£	4,760,000		£	8,900,000		£	12,350,000		All based on Timber/Perspex Cladding
	Series 3000: Landscape and Ecology	£	-		£	-		£	-		
	Tunnel Systems	£	-		£	560,000		£	3,160,000		see break down
	Construction Sub-Total	**£**	**12,490,000**	**57%**	**£**	**17,940,000**	**58%**	**£**	**26,720,000**	**58%**	
	Main Contractor Overhead %	£	620,000	5%	£	900,000	5%	£	1,340,000	5%	5% of construction cost
	Main Contractor Profit %	£	250,000	2%	£	360,000	2%	£	530,000	2%	2% of construction cost
	Total price exc fees	**£**	**13,360,000**		**£**	**19,200,000**		**£**	**28,590,000**		
	Total price inc fees	**£**	**15,610,000**		**£**	**22,430,000**		**£**	**33,400,000**		
	Other Allowances	£	5,880,000	44%	£	8,450,000	44%	£	12,580,000	44%	44%
	Identified Risks and Opportunities	£	-								Optimism Bias as recommended by OGC
	Inflationary Impact %	£	-								
	TM over and above allowance for ALR scheme	£	250,000		£	250,000		£	250,000		
	Other Allowances Sub-Total	£	-								
	Project Total inc fees and Optimism Bias	**£**	**21,740,000**		**£**	**31,130,000**		**£**	**46,230,000**		Based on Q3 2015 prices

Cantilevered canopy 1000m

Item Description	Unit	Quantity	Rate	Total	Ref.	
			2015 rate	Total Estimated Value £	Spons Ref.	
Tunnel						
Series 100: Preliminaries						
Series 200: Site Clearance						
General Site Clearance	ha	50.40	£2,456.12	£123,788.22		
Series 300: Fencing						
				£0.00		
Series 400: Road Restraint Systems (Vehicle and Pedestrian)						
Sub Total				**£0.00**		
Series 500: Drainage & Service Ducts						Inc in tunnel systems
Sub Total				**£0.00**		
Series 600: Earthworks						
Excavation of Acceptable Material Class 5A (topsoil)	m^3		£0.96	£0.00		
Breaking up redundant pavement	m^2		£6.94	£0.00		
Excavation of Acceptable Material excluding Class 5A (Assume 70% of cut)	m^3		£2.29	£0.00		
Excavation of Unacceptable Material Class U1A (Assume 30% of cut)	m^3		£3.02	£0.00		
Deposition of Acceptable Material in embankments and other areas of fill	m^3		£0.89	£0.00		
Imported recycled 6F2 fill in embankments and other areas of the site	m^3		£34.52			
Imported Type 1 fill in capping layer	m^3		£39.82	£0.00		
Disposal of suitable material on site	m^3		£6.96	£0.00		
Disposal of unsuitable material off site	m^3		£43.48	£0.00		
Compaction of suitable material; embankments and other areas of fill	m^2		£0.34	£0.00		
Prep Formation	m^2		£0.45	£0.00		
Sub Total				**£0.00**		
Series 700: Pavements						Excluded from this estimate
Sub Total				**£0.00**		
Series 1100 : Kerbs, Footways and Paved Areas						Excluded from this estimate
Sub Total				**£0.00**		
Series 1200: Traffic Signs and Road Markings						
Large ADS signs on approaches to tunnel						
Large signs on immediate approach						
Direction signs on exits (local and long distance)						
Direction signs						
Misc small signs including lighting provision						
Misc small signs no lighting provision, incl chevrons				£100,000.00		
White lining						
Anti Skid marking						
Allowance for signs						
Sub Total				**£100,000.00**		
Series 1300: Street Lighting						
12m columns	nr	33	£800.00	£26,400.00		
Luminaries	no	33	£450.00	£14,850.00		
Feeder Pillar **(Allowance)**	no	4	£10,000.00	£40,000.00		
Chambers **(Allowance say every 25m)**	no	40	£91.48	£3,659.15		
Ducting and cabling **(Allowance for 6 way duct)**	m	1,000	£17.07	£17,073.18		
Sub Total				**£101,982.34**		
Series 1600: Piling and Retaining Walls						
Establishment of piling equipment				£36,000.00		
Moving piling plant	nr	750	£137.80	£103,350.00		
			£0.00			
Length of bored in-situ conc piles	m	4,875	£114.48	£558,090.00		
				£697,440.00		
Series 1700: Structural Concrete						
Formwork to ground beams	m2	3,500	£56.18	£196,630.00		
Formwork to walls	m2		£82.68	£0.00		
formwork to ceiling	m2		£71.02	£0.00		
Reinforcement	t	140	£1,238.08	£173,331.20		
Concrete	m3	1,000	£153.70	£153,700.00		
			£0.00	£0.00		
			£0.00	£0.00		
			£0.00	£0.00		
			£0.00	£0.00		
				£523,661.20		
Series 1800: Steelwork for Structures						
Steelwork	t	1,181	£1,780.00	£2,102,368.68		
Enclosed ladder	No	20	£4,300.00	£86,000.00		
Rostek Freestanding Guard rail	m	2,000	£65.00	£130,000.00		
				£0.00		
				£2,318,368.68		
Series 1900: Protection for Steelwork						
Zinc primer Paint	m2	11,325	£35.00	£396,367.30		
Sub Total			£35.00	**£396,367.30**		
STRUCTURES						
Series 2500: Cladding						
Wall Cladding						
Timber	m2	13,400	£163.33	£2,188,666.67		
Roof Cladding						
Perspex Fybagard GRP Fire rated	m2	11,600	£220.00	£2,552,000.00		10mm thick
Doors	Nr	10	£2,000.00	£20,000.00		
				£4,760,666.67		
Series 3000: Landscape and Ecology						
Sub Total				**£9,022,274.40**		
SUB-TOTAL				**£9,022,274.40**		
CONSTRUCTION COST				**£9,022,274.40**		

Partially Covered canopy 1000m

Item Description	Unit	Quantity	Rate	Total	Ref.	
			2015 rate	Total Estimated Value	Spons Ref.	
				£		
Tunnel						
Series 100: Preliminaries						
Series 200: Site Clearance						
General Site Clearance	ha	50.40	£2,456.12	£123,788.22		
Series 300: Fencing						
				£0.00		
Series 400: Road Restraint Systems (Vehicle and Pedestrian)						Excluded from this estimate
Sub Total				£0.00		
Series 500: Drainage & Service Ducts						Inc in tunnel systems
Sub Total				£0.00		
Series 600: Earthworks						
Excavation of Acceptable Material Class 5A (topsoil)	m^3		£0.96	£0.00		
Breaking up redundant pavement	m^2		£6.94	£0.00		
Excavation of Acceptable Material excluding Class 5A (Assume 70% of cut)	m^3		£2.29	£0.00		
Excavation of Unacceptable Material Class U1A (Assume 30% of cut)	m^3		£3.02	£0.00		
Deposition of Acceptable Material in embankments and other areas of fill	m^3		£0.89	£0.00		
Imported recycled 6F2 fill in embankments and other areas of the site	m^3		£34.52			
Imported Type 1 fill in capping layer	m^3		£39.82	£0.00		
Disposal of suitable material on site	m^3		£6.96	£0.00		
Disposal of unsuitable material off site	m^3		£43.48	£0.00		
Compaction of suitable material; embankments and other areas of fill	m^2		£0.34	£0.00		
Prep Formation	m^2		£0.45	£0.00		
Sub Total				£0.00		
Series 700: Pavements						Excluded from this estimate
Sub Total				£0.00		
Series 1100 : Kerbs, Footways and Paved Areas						Excluded from this estimate
Sub Total				£0.00		
Series 1200: Traffic Signs and Road Markings						
Large ADS signs on approaches to tunnel						
Large signs on immediate approach						
Direction signs on exits (local and long distance)						
Direction signs						
Misc small signs including lighting provision						
Misc small signs no lighting provision, incl chevrons				£250,000.00		
White lining						
Anti Skid marking						
Allowance of 2% construction cost for signs						
Sub Total				£250,000.00		
Series 1300: Street Lighting						
12m columns	nr	33	£1,900.00	£63,333.33		
Feeder Pillar **(Allowance)**	no	4	£10,000.00	£40,000.00		
Chambers **(Allowance say every 25m)**	no	40	£91.48	£3,659.15		
Ducting and cabling **(Allowance for 6 way duct)**	m	1,000	£17.07	£17,073.18		
Sub Total				£124,065.67		
Series 1600: Piling and Retaining Walls						
Establishment of piling equipment				£36,000.00		
Moving piling plant	nr	250	£137.80	£34,450.00		
			£0.00			
Length of bored in-situ conc piles	m	2,250	£114.48	£257,580.00		
				£328,030.00		
Series 1700: Structural Concrete						
Formwork to ground beams	m2		£56.18	£0.00		
Formwork to walls	m2		£82.68	£0.00		
formwork to ceiling	m2		£71.02	£0.00		
Reinforcement	t		£1,238.08	£0.00		
Concrete	m3		£153.70	£0.00		
			£0.00	£0.00		
			£0.00	£0.00		
			£0.00	£0.00		
			£0.00	£0.00		
				£0.00		
Series 1800: Steelwork for Structures						
Steelwork	t	852	£1,780.00	£1,517,138.50		
Enclosed ladder	No	20	£4,300.00	£86,000.00		
Rostek Freestanding Guard rail	m	2,000	£65.00	£130,000.00		
				£0.00		
				£1,733,138.50		
Series 1900: Protection for Steelwork						
Intumescent paint	m2	23,620	£40.00	£944,800.00		
Sub Total			£40.00	£944,800.00		
STRUCTURES						
Series 2500: Cladding						
Wall Cladding						
Timber	m2	18,800	£163.33	£3,070,666.67		
Roof Cladding						
Perspex Fybagard GRP Fire rated	m2	26,300	£220.00	£5,786,000.00		10mm thick
Doors	Nr	10	£4,000.00	£40,000.00		
				£8,896,666.67		
Series 3000: Landscape and Ecology						
Sub Total				£12,400,489.06		
SUB-TOTAL				£12,400,489.06		
CONSTRUCTION COST				£12,400,489.06		

Fully Covered canopy 1000m

Item Description	Unit	Quantity	Rate	Total	Ref.	
			2015 rate	Total Estimated Value £	Spons Ref.	
Tunnel						
Series 100: Preliminaries						
Series 200: Site Clearance						
General Site Clearance	ha	50.40	£2,456.12	£123,788.22		
Series 300: Fencing						
				£0.00		
Series 400: Road Restraint Systems (Vehicle and Pedestrian)						Excluded from this estimate
Sub Total				£0.00		
Series 500: Drainage & Service Ducts						Inc in tunnel systems
Sub Total				£0.00		
Series 600: Earthworks						
Excavation of Acceptable Material Class 5A (topsoil)	m^3		£0.96	£0.00		
Breaking up redundant pavement	m^2		£6.94	£0.00		
Excavation of Acceptable Material excluding Class 5A (Assume 70% of cut)	m^3		£2.29	£0.00		
Excavation of Unacceptable Material Class U1A (Assume 30% of cut)	m^3		£3.02	£0.00		
Deposition of Acceptable Material in embankments and other areas of fill	m^3		£0.89	£0.00		
Imported recycled 6F2 fill in embankments and other areas of the site	m^3		£34.52			
Imported Type 1 fill in capping layer	m^3		£39.82	£0.00		
Disposal of suitable material on site	m^3		£6.96	£0.00		
Disposal of unsuitable material off site	m^3		£43.48	£0.00		
Compaction of suitable material; embankments and other areas of fill	m^2		£0.34	£0.00		
Prep Formation	m^2		£0.45	£0.00		
Sub Total				£0.00		
Series 700: Pavements						Excluded from this estimate
Sub Total				£0.00		
Series 1100 : Kerbs, Footways and Paved Areas						Excluded from this estimate
Sub Total				£0.00		
Series 1200: Traffic Signs and Road Markings						
Large ADS signs on approaches to tunnel						
Large signs on immediate approach						
Direction signs on exits (local and long distance)						
Direction signs						
Misc small signs including lighting provision						
Misc small signs no lighting provision, incl chevrons				£250,000.00		
White lining						
Anti Skid marking						
Allowance of 2% construction cost for signs						
Sub Total				£250,000.00		
Series 1300: Street Lighting						
12m columns	nr	33	£1,900.00	£63,333.33		
Feeder Pillar **(Allowance)**	no	4	£10,000.00	£40,000.00		
Chambers **(Allowance say every 25m)**	no	40	£91.48	£3,659.15		
Ducting and cabling **(Allowance for 6 way duct)**	m	1,000	£17.07	£17,073.18		
Sub Total				£124,065.67		
Series 1600: Piling and Retaining Walls						
Establishment of piling equipment				£36,000.00		
Moving piling plant	nr	250	£137.80	£34,450.00		
			£0.00			
Length of bored in-situ conc piles	m	2,250	£114.48	£257,580.00		
				£328,030.00		
Series 1700: Structural Concrete						
Formwork to ground beams	m2		£56.18	£0.00		
Formwork to walls	m2		£82.68	£0.00		
formwork to ceiling	m2		£71.02	£0.00		
Reinforcement	t		£1,238.08	£0.00		
Concrete	m3		£153.70	£0.00		
			£0.00	£0.00		
			£0.00	£0.00		
			£0.00	£0.00		
			£0.00	£0.00		
				£0.00		
Series 1800: Steelwork for Structures						
Steelwork	t	953	£1,780.00	£1,696,389.84		
Enclosed ladder	No	20	£4,300.00	£86,000.00		Quote from Rostek
Rostek Freestanding Guard rail	m	2,000	£65.00	£130,000.00		
				£0.00		
Rostek Roofsafe cable system	m	2,000	£31.00	£62,000.00		Quote from Rostek
				£1,974,389.84		
Series 1900: Protection for Steelwork						
Intumescent paint	m2	24,627	£40.00	£985,081.60		
Sub Total			£40.00	£985,081.60		
STRUCTURES						
Series 2500: Cladding						
Wall Cladding						
Timber	m2	17,200	£163.33	£2,809,333.33		Fair faced finished
Roof Cladding						10mm thick
Perspex Fybagard GRP Fire rated	m2	43,000	£220.00	£9,460,000.00		Single glazed galvanized windows
Doors	Nr	20	£4,000.00	£80,000.00		
				£12,349,333.33		
Series 3000: Landscape and Ecology						
Sub Total				£16,134,688.66		
SUB-TOTAL				£16,134,688.66		
CONSTRUCTION COST				£16,134,688.66		

Appendix B – Table of cost comparisons for different material combinations

Structure Form	Wall	Roof	Cost per km, £, million, 2015 prices, rounded
Structure 1	Timber	Perspex	£21.7/10.9*
	Timber	Timber	£20.4/10.2*
		Metal	£17.3/8.7*
		Glass	£29.4/14.7*
	Concrete	Timber	£21.4/10.7*
		Metal	£18.0/9.0*
		Perspex	£22.9/11.5*
		Glass	£29.3/14.7*
	Metal	Timber	£16.7/8.4*
		Metal	£13.3/6.7*
		Perspex	£17.1/8.6*
		Glass	£25.4/12.7*
	Glass	Timber	£30.3/15.2*
		Metal	£26.9/13.5*
		Perspex	£31.9/16.0*
		Glass	£38.3/19.2*
Structure 2	Timber	Perspex	£31.1
	Timber	Metal	£19.9
		Perspex	£31.1
		ETFE	£31.8
	Metal	Metal	£14.7
		Perspex	£26.0
		ETFE	£26.3
	Concrete	Metal	£21.2
		Perspex	£32.5
		Glass	£46.9
	Perspex	Metal	£22.7
		Perspex	£33.7
		ETFE	£34.9
	ETFE	Metal	£23.3
		Perspex	£34.6
		ETFE	£35.8
Structure 3	Timber	Perspex	£46.2
	Timber	Metal	£28.2
		Glass	£71.5
		ETFE	£48.6
	Metal	Perspex	£41.9
		Metal	£23.2
		Glass	£66.4
		ETFE	£43.9
	Concrete	Perspex	£48.0
		Glass	£71.6
		ETFE	£50.1
	ETFE	Metal	£31.7
		Perspex	£49.7
		ETFE	£51.8

Table B-1: Cost variations for different wall and roof combinations for different Structures

All figures rounded to one place of decimal

* indicates provision on both or one side only, rounded up to nearest £0.1 million.