M2

Strandlodsvej Portal Study
Phase 1: Options Comparison

Document ID:		
Version:	2.0	
Issue date:	07/10/2025	
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Pages:	60	

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Revision summary

Version	Date	Scope of revision	Change description
0.1	June 2025	First Draft	
0.2	August 2025	After internal Review	Comments received from internal MS team.
1.0	October 2025	First Issue to KK	All comments incorporated
2.0	October 2025	Reissue to KK	New comments incorporated

1 Introduction

MS has been tasked by Borgerrepræsentationen with preparing a proposal for a planning allocation for covering the open metro trough between the Strandlodsvej portal located south of Lergravsparken Station, and Øresund Station on the M2 Metro line, as well as exploring alternative uses for a cover.

Borgerrepræsentationen has made a budget reservation of DKK 2M to cover MS's costs to prepare concepts.

Figure 1: Strandlodsvej Portal; Aerial View

It is assumed in connection with the planning allocation that the section will be given the status of a switch chamber in a contingency context. It is also assumed that it will be a deck construction that can be lifted into place in sections in connection with night-time closures of metro operations, so that the construction of the cover does not affect normal operations.

It is also assumed that only very limited changes will be made to the railway trench and that no changes are necessary on the adjacent sections.

Finally, it is assumed that the new structures fully meet Metroselskabet's objectives for protection against extreme rainfall and storm surges.

The task is to be solved in two phases, where in phase 1 alternative solutions are screened with regard to construction method and use of the covered area. The phase ends with the selection of one solution. In phase 2 the selected solution is further processed.

This document covers phase 1 of this study and explores several alternative solutions to a light cover, to ensure that the correct way forward is developed.

1.1 Purpose

The main purpose of the cover, as understood by MS, is to mitigate the effects of noise emitted from the metro in the location of the trough between the M2 south portal and Øresund Station.

The rail alignment in the trough includes the tightest radius curve on the entire Copenhagen Metro line. Typically, curves on the alignment cause wear on both rails and metro car wheels, and this wear can on occasion cause more noise than on straight sections.

To reduce this, Metroselskabet keeps in place a suitable maintenance regime to ensure that rails are regularly sanded down to keep them smooth to assist in keeping noise levels down, and a lubrication system is employed on the curve to further reduce noise. The wheels of the car are also maintained and replaced as necessary to ensure that the noise emitted is as normal.

While the maintenance regime is considered adequate, this location is perhaps seen as susceptible to degradation of the rails, more than other parts of the track. Due to the non-linear nature of the rail wear, there may be occasional periods when higher noise levels may be observed, particularly immediately before service intervals.

The intention of the cover is to ensure that noise levels are always kept below the recommended levels.

The scope of this report does not include an assessment of the noise levels that have been observed, nor does it state how this compares with any recommended limits.

1.2 Scope

The scope of this study is limited to proposed solutions between the Strandlodsvej tunnel portal and Øresund Metro Station.

This report will:

- give an overview of the existing structure;
- offer a basis for design of noise mitigation measures;
- highlight key aspects from various critical disciplines that may affect the choice of a solutions;
- describe a number of solutions;
- present a cost and programme summary;
- present a high-level risk assessment;
- present an evaluation matrix;
- conclude on the most advantageous feasible solution; and

- offer a proposal for Phase 2 of this study, to develop a single concept design.

The solutions presented are conceptual only to assist in option selection. Concerns and caveats are covered in later sections of this report, which identify next steps to be taken on a preferred option.

1.3 Applicability

This report is location-specific, and any proposed solutions herein may not be applicable to any other location.

1.4 References

Code	Reference description
1	ØK58 Undersøgelse af overdækning af Amager Metroen

2 Existing Arrangement

2.1 Metroselskabet Assets

The existing trough structure is constructed from walls made of secant piles and steel sheet piles. Secant piles are used at the western end of the trough at the tunnel portal, and are used for 39m of the alignment (Zone A). The remaining 225m length portion of the trough (Zones B and C) are constructed from steel sheet piles. Both the sheet piles and the secant piles rely on ground anchors.

The trough is approximately 11 m wide at the portal, narrowing to 10.3m at the interface between secant piled wall and steel sheet piles (39 m from the portal, Zone A. The trough gradually widens 10.9m through the straight section (a further 103 m, Zone B), before gradually getting wider again to through the curved section (122m) to a final width of 14,2m (Zone C), as shown in fig 2, below.

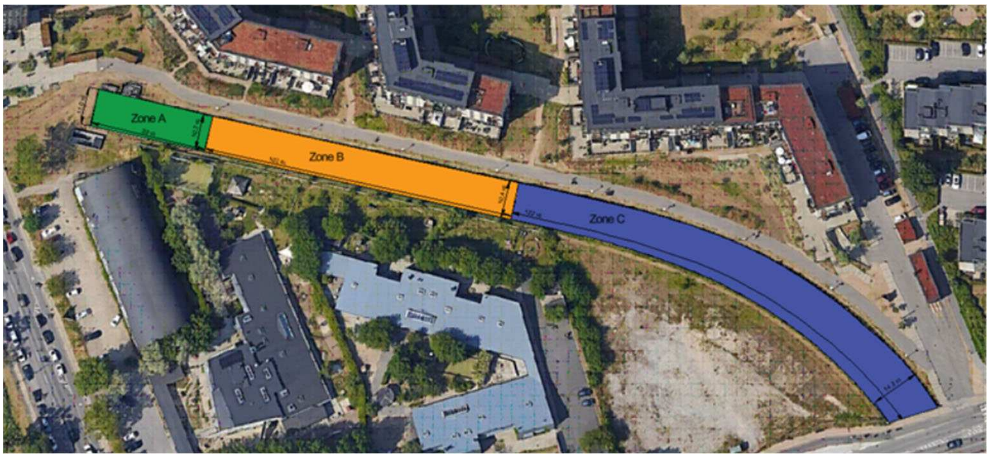


Figure 2: Strandlodsvej Portal Zones

The secant piles in Zone A are a width of 1.65m on each side of the trough,spaced at 1.4m centre-to-centres. The steel sheet piles are a width of 0.45 m either side of the trough. Ground anchors are placed at set spacing along the length of the trough, and extend in plan up to 9 m beyond the inside face of the trough.

These dimensions are important when considering the impact of nearby construction, as any impact to the existing retaining wall assets need careful consideration, with respect to their capacity to undertake their primary task as a wall.

Table 1: Width of trough zones

Zone	Description	Distance from portal	Width (m)		
			Start	End	Nominal
A	Straight Secant Piled wall	0m to 39m	11.0	10.3	14.3
B	Straight Sheet piled wall	39m to 142m	10.3	10.4	11.3
C	Curved Sheet piled wall	142m to 264m	10.4	14.2	15.1

Stairs are located on either side of the portal. The stairs on the north side of the track offer access to the walkway (Northbound), while the southern stairs are located separately from the trough and offer access to the adjacent technical room. Access to these facilities shall not be hindered by any new works.

Figure 3:Portal Escape Stairs

The trough features twin rail tracks, and includes a pair of crossovers in sequence. This track arrangement rules out any possibility of having columns placed in the trough. The track runs on ballasted sleepers throughout.

Figure 4:Crossover Location

The base slab of the trough is 600mm thick, and its upper face sits 600mm below the Top of Rail level. The trough system relies on both vertical ground anchors to tie down the base slab and raked ground anchors tying back the retaining wall and capping beam into the limestone bedrock.

The depth of the trough varies from approximately 9,5 m at the deepest point, rising to approximately 6m at the Øresundvej Bridge.

The inner rail radius is approximately 100 meters and is thus the sharpest curve above-ground outside of the CMCs, which makes the alignment unique.

500-550 trains pass through this section every day.

2.2 Drainage

The trough is currently designed to manage any rainfall that may collect between the trough walls. At the entrance to the tunnel, there is a drain that collects liquids, allowing them to be contained and then removed.

2.3 Adjacent buildings

North of the trough are three blocks of residential buildings built in 2017 varying from 5 to 7 floors, and a residential tower with 13 floors. The ground floor of the residential tower is activated with restaurants, while the three residential blocks have gardens and patios facing the trough on ground level. The gardens and patios are bordered by a 5 m wide green space followed by a pedestrian path. Nestled between the pedestrian path and the trough is a 3 m wide grassed margin.

The south side of the trough is characterised by a triangular plot, which is bordered by Strandlodsvej and Øresundsvej. Towards Strandlodsvej to the west is a covered badminton court with an associated parking space. Adjacent to the covered badminton court towards east are two institutions housing both kindergarten and nursery with associated parking. South of the institutions towards Øresundsvej is a greenbelt with ‘levende hegn’. The institutions’ recreational outdoor spaces are predominantly placed to the north and are directly bordering the trough and its sheetpile walls.The easternmost part of the triangular plot is currently undeveloped and is bordered by Øresundsvej and the curved part of the Metro’s alignment. The undeveloped area is included in detailed area plan no. 503 ‘Lergravsvej’ which was passed in May 2014. The detailed area plan allows the area to be developed into a 6-14 floored parking garage with an activated ground level with retail shops.

The separation between the institution boundary on the outside of the sheet piled wall is of the order of 2 m.

3 Design Objectives

A number of high-level design requirements have been established to assist in the development of potential solutions. These are broadly categorised between those from KK, and those from MS.

3.1 København Kommune Objectives

The initial request from KK is to investigate a cover over the trough. The primary purpose of a cover is to **reduce the noise impact** to local residents. While no clear target noise limit is available, solutions will be assessed to determine what potential noise reduction (in dB(A)) could be achieved by each option.

As well as a full cover, MS will investigate a simpler noise reduction system used elsewhere on the Copenhagen Metro, which utilised noise attenuation panels, which act to absorb sound, and minimise reflected sound from surfaces. We will also investigate options for vertical sound barriers which will offer similarly reduced noise impact to local residents, with significantly lower cost and operational impact.

While a core objective is noise reduction, a number of additional secondary objectives have been identified by KK, as follows.

- Inclusion of a pedestrian or cycle bridge over the trough (as planned for in lokalplan 503)
- Inclusion of solar energy capture technology, for use by a 3rd party, for uses such as car charging or similar.
- Improved biodiversity at the trough, by any possible means.

These topics are considered in Section 5.4, Supplementary Solutions.

3.2 Metroselskabet Objectives

From the perspective of MS, the core objective is to retain the functionality and service availability as a metro system that we have now. Notwithstanding this, a number of incidental enhancements may be possible, and shall be investigated:

- improve the integration of the metro into the surrounding city
- improve the local urban nature
- improve the security in the event of a cloudburst rainfall event
- improve the security in the event of a storm-surge event

The first two items are considered in the evaluation of the options, as they can be achieved to varying degrees in each option proposed. The latter two options are discussed in Section 4.4, under Climate Adaption, to further evaluate the level of requirement on each topic. They are being looked at under a separate study, however, any commonality in the requirements may be considered for combined implementation.

4 Design Considerations

4.1 Contributors to the Design

Evaluation Criteria differ from the requirements, as some requirements are clear that they shall be included, whereas some allow inclusion to some extent. Furthermore, the criteria consider a wider range of topics that we would typically use to evaluate projects. In-house specialists within MS, and external consultants have been brought in to contribute to discussions, including:

- **Structural and civil design engineers**

Our in-house team of engineers will consider the design and constructability of the proposed solutions, including proposals for materials, equipment and access.

- **Geotechnical and Underground works engineers**

The existing trough is an earth-retaining structure, and any works near it shall not negatively affect the performance of the trough. Any new construction will likely have an interface with the local geology, so suitable consideration must be given.

- **Rail Safety specialists**

Our rail safety specialists have experience on our existing infrastructure, as well on in the development, design and construction of new infrastructure, in terms of securing the essential safety approvals required to open and operate a metro system. They understand how emergency scenarios need to be handled, and how the emergency services, such as fire and rescue teams can access the metro system, and how passengers can egress safely.

- **Operations team members**

Operations team members, in collaboration with our operator, possess extensive experience in the efficient management of maintenance and project closures, expertly optimizing closure windows by coordinating activities to minimize operational disruption.

- **Urban Planners**

Our urban planners can help assess how any projects considered at Strandlodsvej Portal may positively and/or negatively affect the surrounding city and local neighbourhood. Our urban planners can also contribute with input that may qualify the project, so it is ensured that the project contributes as positively as possible to the local neighbourhood and citizens. This work will not be part of phase 1 but will have sufficient focus in phase 2.

- **Asset Management Maintenance specialists**

Our asset managers bring expertise in life cycle costs and longer-term requirements. Our maintenance specialists possess deep expertise in implementing effective maintenance practices that extend asset lifespan. Leveraging years of experience, they play a key role in advancing the knowledge and improvement of system uptime and reliability.

- **Cost and program specialists**

Our cost and program specialists are a specialist consultancy working with construction costings and (programme) scheduling. Utilising dedicated Cost Managers/Quantity Surveyors and Schedulers they bring up to date data and analytics to ensure current market rate evaluations of anticipated cost and activity scheduling throughout Project life cycles. This ensures accurate estimating and planning from the earliest stages of design that can be readily scaled up and adapted as design progresses.

In addition to this, we have our in-house commercial team who have a data on metro passenger-numbers and can provide a strong basis on the impact of line closures, and the costs required to put them into place.

- **Sustainability advisors**

The sustainability team at Metroselskabet covers a wide range of sustainability topics, including carbon and resource management and urban nature or biodiversity, which are most relevant to this project.

Carbon accounting and management is integral to construction projects throughout all project phases. Carbon is therefore considered in the design of projects and emission data is collected for most materials. Resources, such as waste, energy, and water, are also important data points to understand the entirety of the project's impact.

Metroselskabet is part of Copenhagen Municipality's Partnership for Biodiversity, which has the main goal of improving urban nature and biodiversity in the city. Even small projects can improve urban nature by including a diverse composition of local plant species and covering both vertical and horizontal surfaces.

4.2 Geology and Geotechnics

Geotechnical conditions are often critical when considering any assets or construction works that have an interaction with the ground. The trough at the M2 Portal is fundamentally an earth retaining wall, relying on ground anchors in the walls and slab to provide a safe stable permanent structure.

4.2.1 Description

To assist in understanding the local prevailing geotechnical behaviour of structures in the area around the trough, the following is a summary of the local subsurface expected to be found in the area between Lergravsparken Metro Station and Øresund Metro Station, on the M2 line:

- **Quaternary Cover**
    - The uppermost layer consists of city fill and urban deposits, often 1–5 m thick, including sand, gravel, clay, organic debris and occasional anthropogenic materials
    - Beneath that lies glacial Quaternary deposits: alternating clay tills (low permeability) and meltwater sands and gravels (higher permeability), typically 10–30 m thick in the metro alignment near Øresund and Amager
- **Paleogene Bedrock – Danian Limestone**
    - Below the Quaternary layers lies Danian limestone, predominantly the København Kalk Formation, sometimes with locally overlying Selandian greensand units
    - The limestone is subdivided into beds of varying hardness:
        - Upper limestone—heavily fractured and highly permeable
        - Middle & lower limestone—more intact, lower permeability
        - Bryozoan limestone—bioclastic layer, also containing flint nodules

4.2.2 Loading

Any proposed solutions to be reviewed to ensure that they do not alter for the worse the structural performance of the existing asset and given the significance of the local geology and hydrogeology upon the trough, the importance of the geotechnical aspects of a new solution must also be considered.

The walls of the trough are designed to provide lateral support to the earth behind. Any application of an additional load on the walls will need to be checked to ensure that the structure still functions as it should.

Additional load may include:

- Load applied to the inside face of the trough;
- Load applied to the top of the walls; or
- Load applied outside of the walls.

Any of these scenarios would require the wall to take more load than designed for.

The walls are not deep, and do not appear to rely on any end-bearing ability. The soil/rock that they are located in would appear to be able to manage the self-weight of the structure, while ground anchors tie the walls into the limestone later, helping to ensure structural stability of the system.

Some general considerations for solutions include:

- Affixing light vertical loads to the inside of the walls is likely manageable, given that retrofitting of items on walls has been done elsewhere.
- Loading on top of the walls would likely develop both axial and bending on the wall, and size of any new works on the walls should be minimised.
- Loading of the ground outside of the trough needs to be considered with respect to the easement rules, as well as the interaction with the existing structures. Near the secant piles, the capping beam is a physical obstruction. Loading of the ground more than the easement surcharge rules permit needs very careful consideration. Moving and loading away from the walls may be required to ensure an acceptable system.
- The ground anchors extend a distance of at least 7m from the inner face of the wall, and damage to them must be avoided.
- Loading outside of the trough could either be:
    - as strip foundations that spread the load over a large area to reduce the pressure on the earth and structures; or
    - As deep piles foundation that transfer high loads to below the zone of influence of the wall. This would require sleeved piles that are effective in preventing the transfer of any horizontal load to the walls.
- Any requirement to modify the existing trough walls should be avoided. Changes to existing structures may impact the status of the rail safety approval. Reassessment is possible, but would be time consuming and carry the risk of not achieving approval.
- Drainage of the area will need to be managed, and could utilise the existing portal sump facilities.

4.3 Utilities and Easements

A preliminary investigation has been undertaken for utilities and easements around the trough at Strandlodsvej by MS Areas and Rights team.

This gave an overview of utilities within 10 meters of the trough. There is an electricity cable (marked in red on Fig. 5 below), which is most likely the cabling for the street lights north of the trough.

The most critical easements are likely MS's own safety easements. These contain, among other things, restrictions regarding excavation and loads. The area can take a load of 20 kPa (1 kPa is equal to 100 kg/m^2). However, it is possible to make a local exemption from this if it can be proven that the impact from the total load within zone A is not greater than the impact that would occur if the entire zone was subjected to a net load of 20 kPa.

The specific landowners have been identified:

- Balder Øresund Strandpark ApS is the owner of the property north of the trough (Cadastre number 1041a Sundbyøster), which is the bicycle path and open space between the 5 housing units located immediately north of the trough.

- Metroselskabet is the owner of the property immediately around the trough (Cadastre number 4535 Sundbyøster).

- The properties south of the trough with the sports hall and institutions are owned by Københavns Kommune (Cadastre numbers 3896 and 3897 Sundbyøster) and the empty lot Skanska Danmark A/S (Cadastre numbers 3772 and 35b Sundbyøster).

The plan in figure 5 shows a mapping of cables and utilities that would have to be considered when undertaking construction in the area.

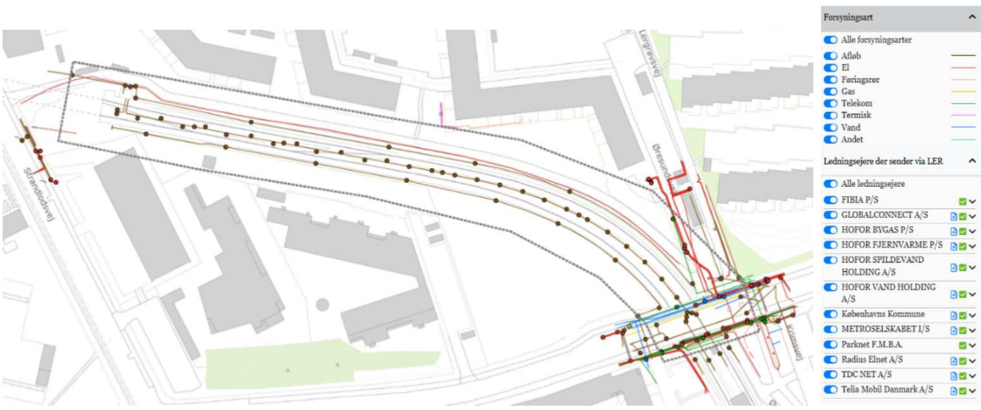


Figure 5: Cables and utilities around the trough

4.4 Climate Adaptation

Possible adaptations to the trough may offer secondary benefits in relation to protection against either future cloudburst rainfall events or future storm-surge events, linked with climate change. Both of these events have been investigated to see what mitigation measures could be desired.

4.4.1 Cloudburst Rainfall Event

In the event of a cloud-burst event, the Strandlodsvej portal area is already adequately protected. No further measures are required to be installed at this location.

However, a cover would protect the track from long term climatic effects, such as repeated inundation events of less severity than a peak cloudburst event. Such benefit may be minimal, when located so close to a portal.

4.4.2 Storm-surge Event

As a preventive measure against a potential storm surge event, the Strandlodsvej portal area may require a flood gate to be installed between the portal and Øresund Station, to prevent storm water flowing into the underground network from the trough area to the south.

In conclusion, no specific additional design requirements relating to climate change effects would need to be included in the design basis for a cover over Strandlodsvej Portal. However, a cover would offer some level of additional protection against long-term effects of inclement weather.

More generally, if a change is made to the trough drainage system, the rainwater that – under the current arrangement - falls into the trough and to the portal sump system, it shall be ensured that the drainage routing to the sump is still in place.

4.5 Noise and Noise Attenuation Measures

The source of noise in the trough is mainly from the friction between the train wheels and the train rails. Noise is typically more noticeable when the alignment is curved. The tighter the curve, the more friction can occur, and more energy is converted into sound.

As the alignment of the curved section north of Øresund Station is the tightest radius on the Copenhagen Metro network, there are already measures in place to assist in noise reduction in this area, with a special system to lubricate the rails as they enter the curve from either direction.

Regular maintenance is undertaken to ensure that the grease application system works, and also that the rails are kept smooth to ensure the lifetime of the system. There is not a requirement to ensure that the recommended noise limit is not exceeded, however, the regular maintenance does tend to ensure that the noise is managed.

Noise heard by the sensitive receptors in the area can be mitigated using many techniques. Aside from directly minimisation of the noise itself, the way the noise reaches the receptors can be mitigated using either:

- Direct noise barrier – blocking the noise directly from the source

- Noise attenuation panels – reducing the effect of reflected noise of nearby surfaces by using sound-absorbing materials

These solutions can be used in combination to great effect and may also be combined with other functionality. Examples of the choice of materials that have been used elsewhere is broad, and the design of the geometry can be critical in helping to direct the noise energy in the most effective manner for the location.

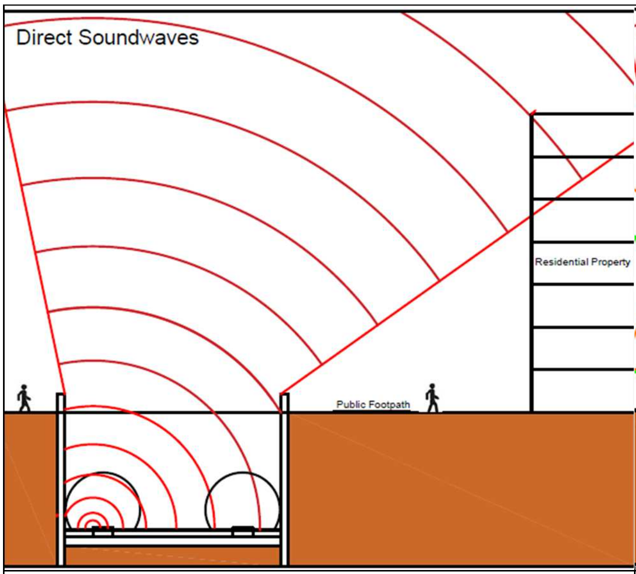


Figure 6: Direct Sound Transmission

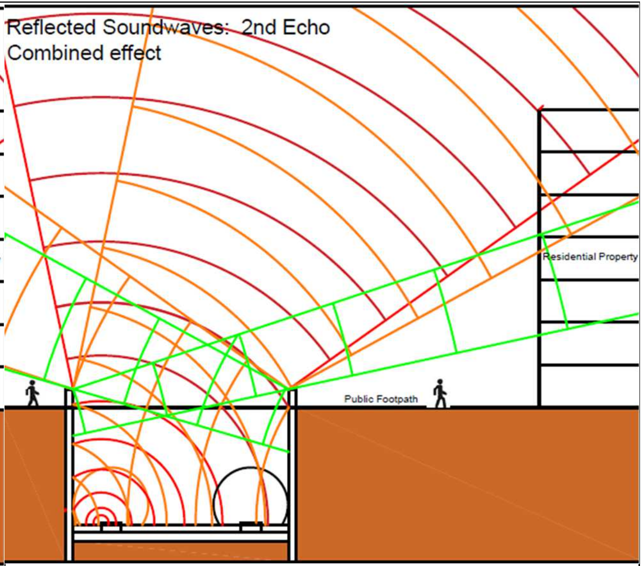


Figure 7: Direct and Reflected Sounds transmission

It may also be possible to offer solutions that increase the biodiversity of the area, by providing 'green' surfaces, such as living walls of vegetation, or sedum.

It may be possible to integrate solar energy capture functionality into the noise barriers, which could be utilised by a 3rd party for numerous purposes.

Possible examples included in the following tables:

Table 2: Barrier Materials

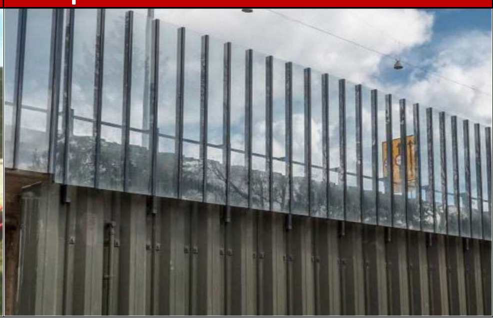
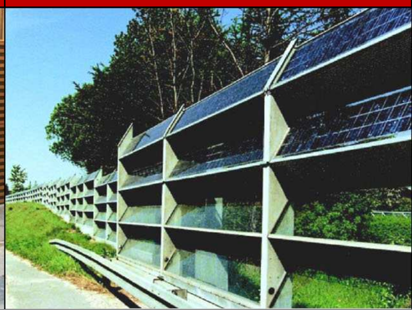
Steel	Perspex	Timber
		

Table 3: Barrier Geometry

Flat	Curved	Horizontal
		
Angled inwards	**Angled outwards**	
		

Table 4: Noise attenuation systems

Cassettes	Solar Panels	Green wall solutions
		

Each option have their own benefits and disadvantages, which need further analysis at the next phase, together with a clear goal for the performance requirements, visual impact, as well as construction and maintenance costs consideration.

The potential for noise reduction varies, depending on the products used.

- A simple barrier can reduce the noise by 2-5 dB(A) relatively easily.
- Increasing the performance to up to 10 dB(A) is possible, but typically requires barriers of significant size.
- Reduction of up to 15 dB(A) requires large barriers of very high performing material and is hard to achieve fully.
- A reduction of 20 dB(A) is typically practically impossible to achieve.

Noise barrier and noise attenuation products must be selected not simply on required volume reduction, but on what frequency of sound is required to be reduced. For example, a high-pitched squeak may need a very different solution to a low rumbling drone. Further analysis is required to ensure the right products are selected.

Noise attenuation products can also act as fire protection systems, and through careful design, they can serve to protect structures from the adverse effects of a fire event.

For this study, solutions will be developed that offer a typical off-the-shelf arrangement of average thickness that can be easily adapted at future stages.

4.6 Disruption to Operation

Any new construction or modification to existing assets can cause disruption to metro operations. This could be through direct impact due to forced closure, or by secondary effects. Some of the key considerations are discussed below:

Any invasive work that causes vibrations near the metro system can impact assets in unexpected ways, thus leading to operational disruptions and shortened lifecycle and/or increased maintenance costs. Tasks that can cause vibration include drilling, welding, hammering and temporary loading of existing structures. The potential impact of any solution should consider how the installation and operation could cause long term effects to the design lifetime, and any potential changes to the maintenance regime.

When considering the passenger impact of any proposed solution, the biggest concern is the need to close the track for construction works.

The Metros customer promise is 24/7 operation. We provide, and our customers rely on, fast, frequent and uncomplicated travel. Any projects that can impact operation are therefore subject to rigorous long-term planning to minimize the impact.

A maintenance regime has been implemented with trackside works occurring most weeknights that can take place while also keeping metro operation running. The schedule is efficient and thus implementing projects (additional work) in this maintenance windows carry a risk of degraded operation (lower frequency of trains).

Some of the required maintenance activities require a stop of operation on the whole line. Therefore, 7 weeks a year, operation is stopped on some weeknights, and replacements buses are inserted, leaving time due for critical activities as well as other works or reinvestment projects. Other projects (such as those discussed in this report) would therefore normally also be required to be executed ***only*** in those time-frames.

Any option that allows operation to continue with only a single-track service is much better than no service (double-track possession), as the night closures of a single track can still offer service. A full/double-track closure would trigger the need for rail-replacement bus services to allow journeys to be completed, causing significant cost (to MS), poorer service and delays to passengers, which may cause a drop in long-term passenger numbers.

Once a preferred option is identified, a detailed analysis of how closures (partial or full) could be managed, shall be undertaken.

Any closures, either partial or full, will have an impact to revenue.

- Partial closures where shuttle service is activated means that customers are forced to change trains, meaning that our service is affected negatively, as travel time increases, and this has a tendency to reduce ridership.

- Full closures have more severe impact. The train is replaced by a Metrobus between stops, which has multiple negative impacts:

    - The costs associated with providing the Metrobuses, and ensuring people are aware of the closure. This cost is relatively straightforward to determine.

    - The loss of revenue associated with passengers choosing to travel by other means. MS have data on this to estimate the impact to revenue.

    - The loss of revenue due to long-term behavioral changes in the way people choose to travel, due to the reduced service, and perceived unreliability of the service.

Further to any assessment of temporary closures, either partial or full, an assessment shall be made to estimate the likely cost impact associated with each option, to allow a reasonable comparison to be made.

A further consideration is the long-term disruption to operations that may be realised if the assets are modified. The current open trough arrangement requires relatively low maintenance. Any changes to the structure, including additional assets to be built would increase the amount of overall maintenance that could be required, this included, but is not limited to:

- cleaning;
- inspection;
- replacement; and
- maintenance.

Each of these aspects could lead to further partial or full closures over the lifetime of the asset and should not be ignored.

4.7 Safety

Any proposed solutions at Strandlodsvej are likely to involve rail safety to some extent. As we are considering modifications to the M2 metro line, it is essential to recognise that any changes may significantly impact the existing safety approval of the system.

The M2 line was originally approved more than 20 years ago under BoStrab and NFPA 130 standards. Since then, both regulatory frameworks have evolved, and

MS must therefore assess how each proposed solution may affect the current safety certification.

4.7.1 Tunnel Extension and NFPA 130 Compliance

A key issue of a proposed covering of the trough is that a change of this type effectively constitutes an extension of the existing tunnel, and as such, the new covered section must be treated as a new tunnel under NFPA 130. This classification triggers a range of safety requirements, including but not limited to:

- Egress routes and travel distances
- Location of the nearest safe area
- Stairways and wheelchair-accessible refuge areas
- Tunnel ventilation and smoke control
- Fire resistance of structural elements

Regardless of the final design solution, these aspects must be thoroughly investigated and documented.

4.7.2 Tunnel Definition and Segment Separation

If a cover is not extended directly from the portal, but from a distance away (effectively creating a new separate tunnel), it may be that safety rules may differ. NFPA 130 does not specify a fixed minimum distance between separated tunnel sections to determine whether they are considered separate tunnels. However, in practice, an open-air separation of approximately 100 meters is often used as a benchmark to break tunnel continuity, provided it allows for natural ventilation and prevents smoke and heat transfer.

If the portal cover does not meet these criteria, the entire structure may be considered a continuous tunnel, requiring full compliance with NFPA 130 for the entire length, including the new section.

4.7.3 CFD Analysis and Safety Strategy

To support the classification and safety strategy, Computational Fluid Dynamic (CFD) analysis should be conducted on the chosen solution. This will help determine:

- The extent to which the portal can be covered without compromising ventilation and smoke control.
- Whether the new section can be treated as a separate tunnel
- The appropriate safety measures and design requirements for the new versus existing tunnel sections

The results of the CFD analysis will guide the safety approval process and clarify which parts of the system must comply with updated NFPA 130 requirements.

CFD analysis will not be possible at this phase, but once a preferred solution is identified, it may be undertaken at Phase 2.

4.8 Tunnel Ventilation Systems (TVS)

With regard to the behavior of modification to the trough structure, using a cover system, with specific regard to the impact of cover on general fire and smoke systems, it must be assumed that any cover needs to be designed to the same fire category as the tunnel, as it will need to deal with same fire load.

An investigation is required to check if the fire-fighting (water) mains would need to be extended or if there is an existing hydrant system available on the surface.

Furthermore, an investigation to check if the existing TVS can still be used for smoke ventilation for the extra 270 meters.

If the existing TVS doesn’t have enough capacity, there are 2 options:

- A shorter cover can be constructed to avoid introducing tunnel ventilation. Typically, a separate independent tunnel no longer than 100m would not require a TVS system.

- Rather than a continuous cover, the solution would feature a series of openings in it, to assist with smoke exhaust. This could either be via grilles at the side, or on the top.

The internal geometry of a covered trough may also need consideration, as creation of a plenum over the tracks may cause unwanted build-up of smoke or other gases, so adequate venting is likely essential.

In both the options, the cover may be required to start a distance from the tunnel (maybe 10 meters from the portal), to avoid any complications with existing TVS.

If any type of cover is proposed, it is essential that a CFD analysis is performed to finalize the length of covers, and size and distance between the openings.

Such analysis can also be used to assess the impact of wind on smoke as we have a road bridge at the south end of the alignment, the two institutions to the south of the trough, and residential buildings on the north side of the trough, none of which should be negatively affected by a new system.

4.8.1 Fire resistance

Any proposal for new construction near the live metro must adhere to the structural fire regulations. Additional fire protection may be required to any system put in place. The requirements are hard to determine before a solution is developed, as the requirements are often steered by the form, and may be affected by the tunnel ventilation system requirements, including position of passive outlet vents. Steelwork in particular may require additional treatment, such as cladding, or intumescent paint coating to ensure structural stability in the event of a fire event.

4.9 Constructability

The constructability of a solution takes into account many of the aspects already mentioned, including the existing structure, the geology, the area around the trough that we are permitted to use (or implications of requiring more), the type of equipment required, the necessity to close the metro (partially or completely) and not least of all, the proposed solution its self.

4.9.1 Worksites Opportunities

For any construction work, an area is required to be set up for storage of material and equipment, deliveries, and welfare facilities. While this could be off-site, the area enclosed between the trough, Øresundsvej, and the institution would seem to offer adequate space for a suitable worksite.

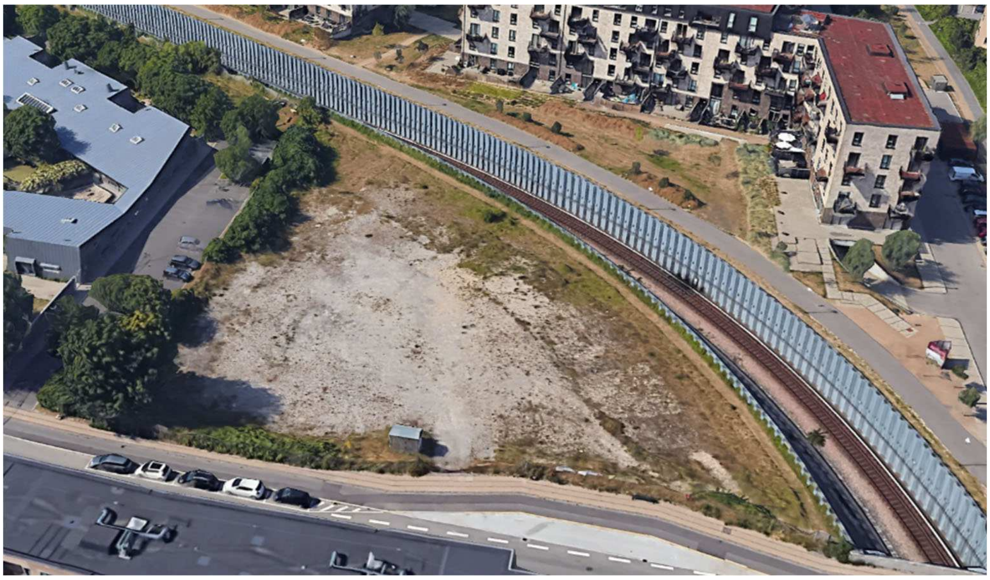


Figure 8: Potential Worksite – South Location

Occupying a triangular area of approximately 4000 m^2, it is readily accessible from a 75m frontage along Øresundsvej, and directly adjoins the trough.

This site offers ample space for welfare, storage, and deliveries, while offering unobstructed access to a quarter of the trough walls.

A well-placed tower-crane with reasonable capacity (say 200 tonne-metres) would be able to access perhaps an 80-100m long section of the trough, easily suitable to handle light construction lifts over the curved section. With some consideration it may be feasible to access 75% of the trough from multiple crane set-ups in the area. (A 200 tonne-metre crane can lift a 4 tonne load at 50m, or a 2 tonne load at 100m)

This site would also be adequate to allow for some workshop facility to allow some assembly of prefabricated elements before lifting parts into place.

On first inspection, an alternative or supplementary worksite may be possible in the area directly above the portal. This area is smaller, at only 600m^2, but benefits from access directly from Strandlodsvej. Due to the location over the existing tunnels, there will certainly be limitations on loading that can be applied to the site. More of a concern are the requirements for this area to serve as a location for access and egress from the tunnel in an emergency – which almost certainly rules this area out as use for a worksite.

Figure 9: Potential Worksite – West Location

4.9.2 Construction works

The method of construction is dictated by the form of the works required, but considering the more ideal options before solution is helpful.

Solutions that can be installed quickly, with the single-track night closure windows are dramatically more attractive than any option that requires full-track closure. This leads us to consider use of prefabricated modular solutions that can be (largely) lifted into place quickly, piece by piece.

Generally speaking, double-track closures are expected to be required throughout the works, unless they can be assessed to be reduced to a single-track closure, through a more detailed study and risk assessment.

Full track closures shall be avoided unless absolutely necessary. Options may be developed and assessed to see how they can be undertaken, taking into account the cost associated with closures, which will include loss of revenue, cost of Metrobus operations, as well as long-term passenger behaviour effects associated with short term closures, that typically lead to extended revenue losses.

The night closure window of 195 minutes every night can allow a well-organised team to perform a variety of tasks, however the overall duration would be significant, and the cost associated with short-shift working should be recognised. However, the cost impact compared to a full-closure shall be considered at a high level.

Each proposal will be assessed to see how many night closure windows may be required to undertake the work, considering if full closure or partial closure is necessary. Tables are provided throughout to indicate expected closure windows.

4.10 Design and Design Life

The design of the solutions must take into account all considerations mentioned in the section. An overarching requirement is that a design life of 100 years is required – and if this is not possible, then the life cycle analysis must take into account the costs of replacement of the assets, such that the design life of 100 years is achieved. The design life for individual components will be estimated for each option proposed. The cost estimation will take account of any replacements works required over the 100 year lifetime.

4.11 Urban Planning

The trough and portal itself is part of detailed area plan no. 360 'Østamagerbanen' passed in January 2003. The plots north of the trough and the portal, as well as the undeveloped part of the triangular plot south of the curved alignment of the Metro, are part of detailed area plan no. 503 'Lergravsvej' passed in May 2014.

The remaining plots south of the trough housing the covered badminton court and the institutions are part of detailed area plan no. 346 'Østamager III' passed in 2001. Depending on the chosen solution it would be necessary to assess which of the detailed area plans that could be affected by the project, and in collaboration with Teknik- & Miljøforvaltningen assess whether updates and/or dispensations are needed, in which case Metroselskabet will deliver the input required.

When choosing a solution from an urban planning perspective, it is necessary to be aware of how it may affect the surrounding urban environment. It will be beneficial to conduct an initial screening of the project, which amongst other things conducts an overall assessment of:

- The visual impact – architecture and aesthetics.
- The potential glare onto surrounding built environment or on street level (traffic safety).
- How the project may affect perceived safety around the trough, the pedestrian pathway and the neighboring buildings.
- How the project may affect the customer experience for commuters arriving to Øresund Station from the north.
- The project's potential shadow impact on surrounding urban space, the neighboring gardens and the patios, the recreational outdoor space for the institutions and the general built environment north and south of the trough. How the project may affect the current possibility of development on the undeveloped plot south of the Metro's curved alignment.
- How to integrate the project into the local neighborhood best possible.

In Phase 2, it will be essential to collaborate with TMF, Miljø and the local plan team, to make sure that the citizens' points of view and concerns are included in the development of the solutions.

5 Descriptions of Proposed Solutions

5.1 Option A: Heavy Cover

5.1.1 Proposed Solution

We have considered a solution that will effectively allow almost anything to be placed above the site – effectively fully enclosing the tunnel. This option will allow for the area above to be built over (light weight buildings only), used for parking, or used for recreational facilities.

The construction works are significant, and the disruption to operations will be challenging, but as a comparisons exercise, it offers a useful perspective.

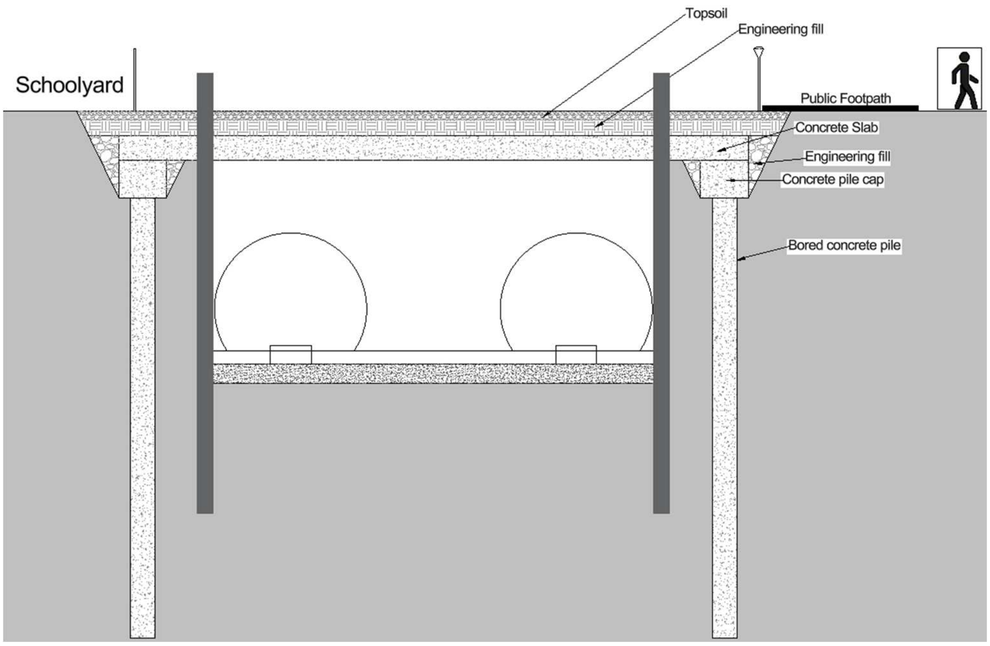


Figure 10:Option A - Section

The option includes the following components:

Foundations
New piles are placed either side of the trough. The piles must be placed an adequate distance from the existing walls to ensure they do not affect them. It is suggested that the piles are cased to a depth below the zone of influence of the trough. Piles are placed in pairs with pile caps, such that they allow a two-way spanning slab to be supported from them.

Piles can be installed during single track closures on each side, however, on the south side, it would require significant expropriation through the institution property.

Modifications
The sheet piles and secant piles would need to be cut to allow a roof slab to be placed above them. The anchors would not be affected, but open excavation would be required to ensure the top of the trough could be lowered. This is a

highly complex aspect that would require detailed analysis and planning to ensure the stability of the trough throughout the works. The safety case during the temporary case will need careful consideration, as it is a high-risk part of the works, due to necessary modifications to the existing structural system.

Roof slab

A roof slab is placed spanning over the foundation pads would need to be cast in-situ, using a system of sliding formwork. The option of using precast slabs lifted into place has been ruled out, due to the weight of the slab, and the easement restrictions that severely limit the use of a high-capacity crane in the area.

It is not possible to construct the slab easily in the area adjacent to the secant piles. At this stage, a 39m long opening is shown. In reality, the opening could be protected using another option. For the purpose of this report, we have applied costs to cover the opening using Option B, presented in section 5.2 of this report).

The concrete slab and ground cover above it will provide a noise barrier that will reduce the noise emissions from the trough effectively. However, it may focus the noise impact around the new portals, located at the east and west end, which may need additional measures to be installed.

Figure 11: Option A - Plan

Surface

It is suggested that a simple grassed area is provided, offering a park area above the tunnel. It would be for a third party to determine a use for the area. The roof slab is covered with an engineered fill, then covered with topsoil before turfing.

Design Life

The design lifetime of this solution is estimated to be 100 years.

Table 5 Design Life of Materials – Option A

Item	Design Life
Piled foundations	100 years
Pile caps	100 years
Fill materials and top Soil	100 years
Roof slab	100 years

Construction

The excavation of the foundations using piling equipment and light plant is not possible during metro operations, and would require a single-track closure during this works.

The modifications to the sheet piles would require full track closures, due to the equipment required to be used within the trough.

The casting of the concrete slab would require a series of full track closures. The initial set up for a formwork system would require an extended full track closure, and it is suggested that the pours also take place over a series of nightly full track closures.

The surface works would not require any track closures.

Table 6 Closure type for various work - Option A

Item	Closure Type
Piled foundations	Single-track night closures (3 hrs)
Pile caps	Single-track night closures (3 hrs)
Fill materials	No closure required
Roof slab	Double track night closures (3 hrs)
Topsoil	No closure required

5.2 Option B: Light Cover

5.2.1 Proposed Solution

A light covering structure has been proposed to cover the trough, and is composed from the following component parts:

Foundations
A concrete strip foundation is required adjacent to the outside of the trough wall to spread the load of the structure. Careful consideration is required to ensure that the foundation does not clash with either the secant pile caps or the ground anchors. This will be very challenging in the vicinity of the institution boundary, as space and access is very limited

Portal Frame
A steel frame shall span the trough. Anchored firmly into the foundations on each side, the frames shall be positioned every 5 metres, along the trough. The columns and beams are of standard steel section, and shall be welded and liftable into position, allowing rapid installation during a series of night-closures.

The frame will be braced laterally by light steel purlins, which will also assist in supporting the roof and wall, and noise insulation, that are expected to be required, as a steel frame alone is unlikely to provide adequate noise insulation.

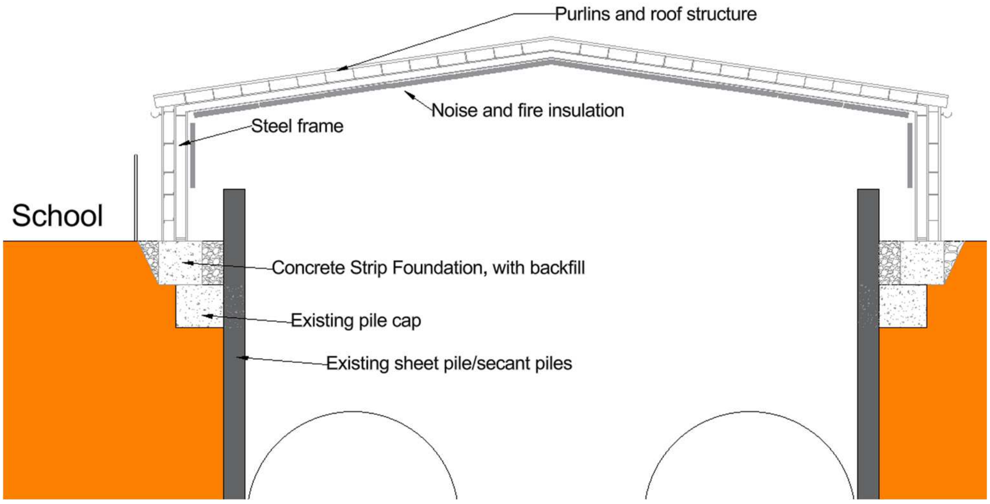


Figure 12: Option B - Section

Roof and wall covering
The roof and wall material will be simple, steel composite material providing ample protection and security.

Figure 13: Option B - Plan

Noise insulation

Although the roof and wall will offer some basic noise reduction, we have considered that a noise insulation layer will also be required. A noise insulation layer can be selected to achieve the desired noise reduction, and has the benefit of also providing fire resistance to the steel structure, which would be required.

Drainage

A simple drainage system will be included, that will take rainwater from the roof to the portal sump. This is where any water falling in the trough would be managed. No additional measures are required.

Ventilation Openings

No openings are shown at this stage – any opening that may be required following analysis of smoke behaviour can likely be included as a no-cost option.

Design Life

The design lifetime of this solution is estimated to be 100 years for the foundations and 50 years for the superstructure.

Table 7 Design Life of Material - Option B

Item	Design Life
Strip foundations	100 years
Portal frame	50 years
Roof and Walls	50 years
Insulation	50 years
Backfill	100 years
Drainage	50 years

Construction

The excavation of the foundations using lightweight equipment is not possible during metro operations, and would require a single-track closure during this works.

The portal frames are expected to weigh less than 1 tonne each and could be lifted in during a series of full track closures.

The purlins and outer wall and roof structures, as well as the noise attenuation materials could be largely installed during single track closures. However work required to the centre of the frame would require a full track closure.

Table 8: Closure types for various work – Option B

Item	Closure Type
Strip foundations	Single-track night closures (3 hrs)
Portal frame	Full -track night closures (3 hrs)
Roof and Walls	Single-track and full -track night closures (3 hrs)
Insulation	Full -track night closures (3 hrs)
Backfill	No closure required
Drainage	Single-track night closures (3 hrs)

5.3 Option C: Noise Barriers and Attenuation System

As an alternative to a cover, it is possible to reduce the noise impact to the local receptors using noise attenuation panels. Such systems are already in place in other locations on the metro system, as well as by other transportation infrastructure works in both Copenhagen and around the world.

The geometry of the trough, and the noise profile emitted from the metro is not like other examples, and as such, it may not be possible to exactly mimic tried and tested solutions, but investigating a more simple system to reduce noise impact would seem sensible.

Two parts to the option are proposed:

- **Option C1: Noise barriers above the trough wall.**
  A noise barrier would be constructed outside of trough, so as not to induce any extra load on the existing structure.

  Such a system would help reduce directly emitted noise to local residents. The barrier would be need to sufficiently high to prevent direct noise from impacting the local residents, specifically on the upper-most floors.

- **Option C2: Noise attenuation panels within the trough**
  Noise attenuation panels are proposed to be fixed to the trough walls on each side, from as low as possible, to as high as practical.

  Such a system would reduce reflected noise echoing off the rough walls, but would have no effect on directly emitted noise reaching local residents.

The two parts are combined to form Option 1, however the extent of each of these aspects is subject to analysis. An illustration of what could be possible is presented below.

5.3.1 Option C1: Noise Barriers

Noise barriers would have to have vertical size large enough to provide a tangible benefit. Above a certain height, they offer negligible additional benefit to reduce noise further. Based on the distance to local residents, a barrier as close as possible to the trough would allow for the lowest barrier height. If placement further way from the trough wall were considered, the higher the barrier would need to be to be equally effective. Placement as close as possible is therefore preferred.

We propose that a barrier is placed directly on top of the sheet pile, as this offers the shortest barrier height, and causes the least disruption with regard to easements. Its main disadvantage is that it would directly load the wall, but after consideration, an assessment of the impact of a barrier placed adjacent to the wall would be required in almost every conceivable case.

The extent of the application of barriers is subject to further analysis, such that the design can ensure the adequate performance of the barriers. The height has been designed to ensure receptor benefit is optimised. Similarly, the linear extent of the noise barrier is subject to analysis. It may be more cost effective to only place barriers on the north side of the trough, to protect the residents, as the facilities to the south may not be so sensitive.

It is essential that the capacity of the sheet piles is checked to ensure that they can handle the additional load that shall be applied by the barriers placed on top of them. The piles are not specifically designed for vertical load.

Design Life
The design lifetime of this solution needs to be confirmed by the supplier of the proprietary products but estimated to be between 25 and 50 years. For the purpose of a full life cycle cost estimate, we have assumed a value within this range.

Table 9: Design Life of Material - Option C1

Item	Design Life
Barriers	35 years

It is expected that this work can be entirely undertaken from ground level, although to reduce the risk of falling items on a live track, a single track closure is proposed on the near side track to the works.

Table 10: Closure type for various work - Option C1

Item	Closure Type
Barriers	Single-track night closures (3 hrs)

5.3.2 Option C2: Noise Attenuation Panels

Noise attenuation panels are proposed to be used on each side of the trough wall. There are some limitations to the precise placement, due to existing services and access to the anchors – so placement above and below the obstructions is suggested.

The performance of noise attenuation panels can vary dramatically, depending on the desired target impact – as mentioned in Section 4.5.

Design Life
The design lifetime of this solution is estimated to be 35 years for the barriers.

Table 11: Design Life of Material - Option C2

Item	Design Life
Noise attenuation panels	35 years

Construction
The installation of the noise attenuation panels would be undertaken from within the trough and would require a stop to operations on the near track during installation of the barriers. The nighttime service window may not be adequate to enable the lifting equipment to get to and from the site and allow a reasonable

amount of work to be done – so a larger duration of single-track closure is envisaged. Full closures are not expected to be required.

Table 12: Closure type for various work - Option C2

Item	Closure Type
Noise attenuation panels	Single-track night closures (3 hrs)

5.3.3 Proposed Solution Option C

It is proposed to combine both Options C1 and C2 to offer a better overall solution.

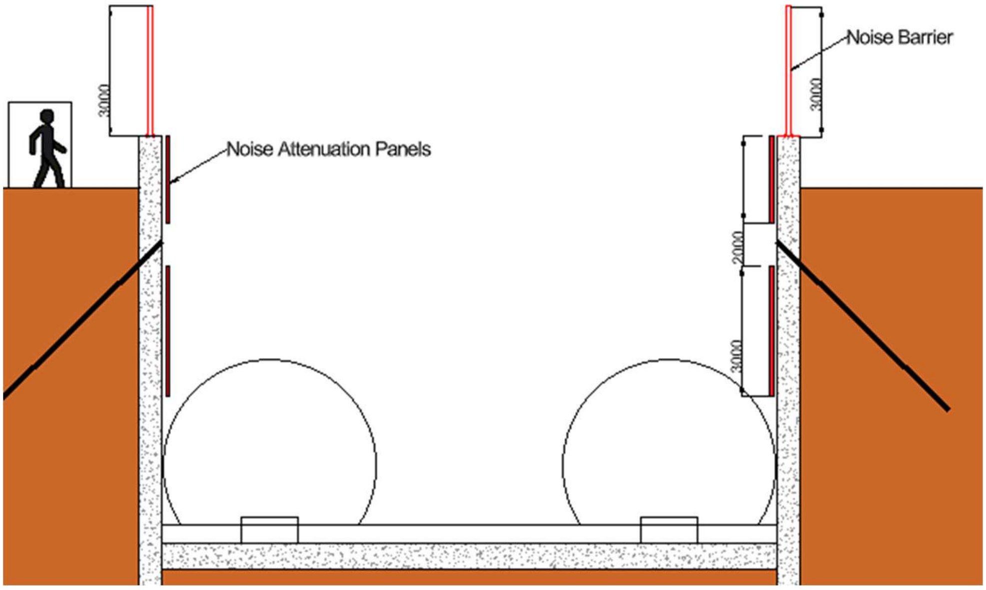


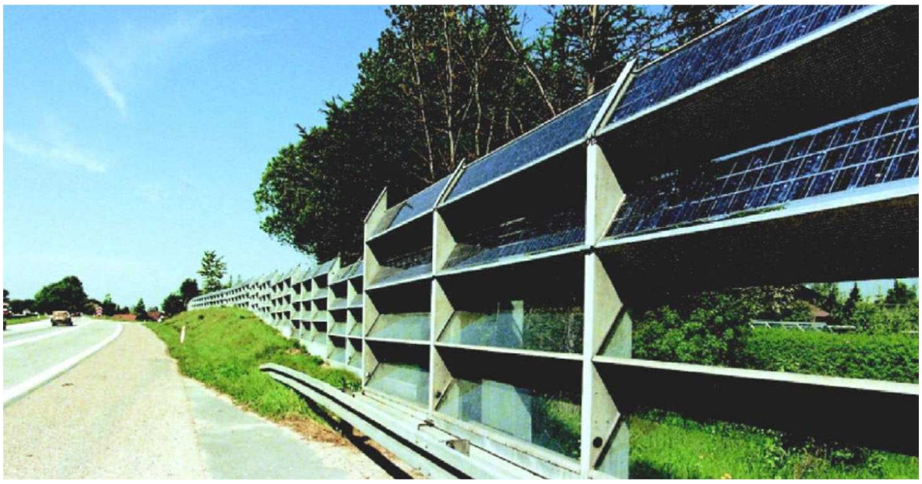
Figure 14: Option C - Section

Figure 15: Option C – Plan

5.4 Supplementary Solutions

A number of supplementary solutions have been discussed, that can be applied to a the options, as follows in Table 16:

Supplement	Description
Green walls, Green roofs **Option B and C**	Application of green walls can be readily applied to either the noise barriers, or to the walls of the light cover. Considerations must include the long-term maintenance of the walls, considering both the durability of the walls, and the management of the vegetation, to ensure they neither die prematurely, or thrive so successfully, that they become a nuisance and negatively impact the structure. A green wall can be a simple as including climbing mesh or wires to encourage vegetation to take a hold, or could be more complex planter-boxes, that include soil substrates and irrigation systems to promote a more rapid formation and managed system. The composition of plants for green walls can be chosen to match the local area or fulfil a certain function such as attracting a certain type of insect or bird. Most importantly the plants should be diverse species that are native to Denmark. The first three years after project completion require more maintenance than subsequent years and must be included in budget and maintenance plans. During this period, it should be expected that some plants will need replacement. A green roof may include a sedum type of roof coverage, that has been successfully used in Copenhagen on a variety of structures, requiring minimal long-term maintenance. Sedum roofs are often supplied as complete solutions that include drainage, soil, and vegetation.  **Figure 16: Sedum Roofs at Norreport**

Solar energy capture **All options**	Including solar panels has been requested by KK. There are examples of inclusion of solar cells on noise barriers, while proprietary products can readily be applied to Options B and C. The biggest challenge with incorporation of solar energy capture is how to manage the interface between the metro asset over the railway, and any energy capture assets (owned and operated by a third party) on top of the asset. Currently, MS has no use for extra power at this location.  **Figure 17: Solar Cells within Noise Barriers**
Footpath/cycle path **Options B and C**	The inclusion of a footbridge/cycle bridge over the tracks could be incorporated at the same time as a cover. The span is comparable with typical road and rail overbridges, and something similar has potential to be included in the solution. Any such proposals would require consideration as to how to ensure protection from noise, likely with the addition of noise insulation panels. The bridge structure would also need to ensure security to the rails below, and should prevent any opportunity for litter or debris to fall on the tracks.  **Figure 18: Overbridge on a mainline rail station**
Overbuild/carpark **Option A**	Option 3 has been configured to allow a reasonable amount of surcharge to be applied, and subject to analysis, could theoretically support a low level multi story building, or equivalent. It could also potentially support a shallow story parking facility, or an EV charging facility. Situated over the metro track, sewerage may be problematic, so small business, small light industrial facility or residential property may be ruled out.

6 Cost and Program Estimate

Metroselskabet have used an independent consultant to estimate the construction cost and program. Metroselskabet have also undertaken a separate consideration of what the program impact on cost and loss of revenue is estimated to be.

- Expropriation Costs
- Life cycle costs, considered at Net Present Value
- Closure costs and lost revenue

These costs are elaborated upon, below:

6.1 Construction Cost Estimate

The construction costs have been developed to 2025 Q3, and includes high level breakdown of material and labour.

6.2 Construction Program

The construction programme has been developed considering the number of personnel required on site, and the duration of each task. An allowance for short shifts working through the short night-time closure windows has been developed, which has then been used to assist in a more realistic cost estimate, and also the duration of temporary land expropriation, as well as closure costs and lost revenue calculations. It is unrealistic to close the metro for a double-track possession every night, so the overall program is based on a limitation of no more than three double-track closures per week.

Table 13: Construction Programme and Closure Summary

Option		Description	Single Track Posessions (nights)	Double Track Possesions (nights)	Total Duration (Months)
Heavy Cover	**A**	Full concrete cover	60	474	**40**
Light Cover	**B**	Steel frame	65	360	**31**
Barriers and Noise Attenuation	**C**	Barriers and noise panels on each side over full length	135	0	**7**

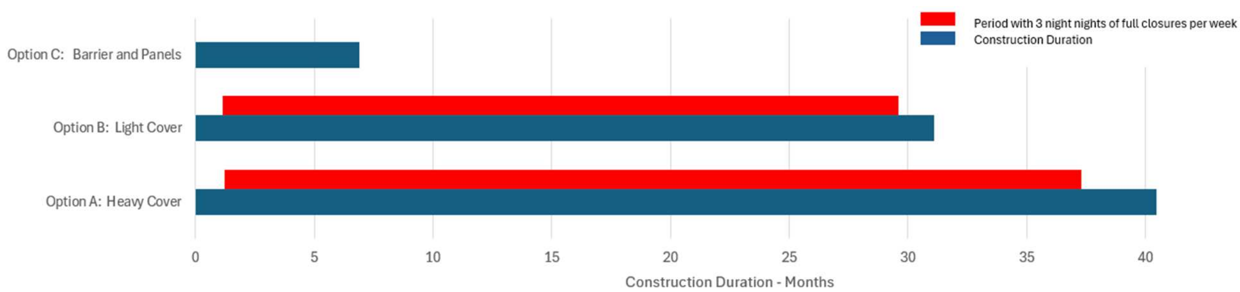


Figure 19: Construction Program Comparison Chart

6.3 Expropriation Costs

Cost of temporary and permanent land expropriation, to cover the area required for the structures, as well as the worksite. This has been based on conservative land value costs. These costs are subject to a more detailed consideration in Phase 2 of this study.

Table 14: Temporary and Permanent Expropriation Costs

Option		Description	Expropriation Costs (M kr)		
			Temporary Land Rental	Permanent Land Purchase	Total Expropriation
Heavy Cover	**A**	Full concrete cover	17.3	24.7	42.0
Light Cover	**B**	Steel frame	12.7	17.9	30.7
Barriers and Noise Attenuation	**C**	Barriers and noise panels on each side	2.9	8.7	11.6

6.4 Closure costs and lost revenue

Closure and lost revenue costs are related directly to the full track closures required to undertake the construction works, as stated in Section 5

- Single track closures last 3hrs 15 mins, but incur closure costs for 5 hrs.
- Single and double track closures incurs costs for lookouts during the shift
- Double track closure costs incur costs to run replacement bus services
- Lost revenue relates to the losses related to passengers not buying tickets due to closures. We have taken into account the future ticket price increase for journeys to the airport in 2027.
- A 5% allowance is included for the after-effects of a closure, that tend to cause a reduction in revenue for the period immediately after closures.

Table 15: Closure and Lost Revenue Cost Summary

Option		Description	Closure Costs (M kr.)		
			Direct Closure	Lost Revenue	Total
Heavy Cover	**A**	Full concrete cover	23	13	**35**
Light Cover	**B**	Steel frame	18	10	**28**
Barriers and Noise Attenuation	**C**	Barriers and noise panels on each side	2.1	1.4	**3.5**

6.5 Life cycle costs

Life cycle costs include the following items

- Annual inspections
- Minor maintenance (scheduled every 10 years)

- Major maintenance, essentially the cost of replacement of individual items over the 100 year design life that do not have a design life of 100 years. This has been based on the design lifetimes stated in Section 5.

We have prepared the cost as a Net Present Value estimate over 100 years, using the appropriate discount factor.

Table 16: Life-cycle Maintenance Costs

Option		Description	Lifecycle Costs (M kr)
Heavy Cover	**A**	Concrete cover	182
Light Cover	**B**	Steel frame	279
Barriers and Noise Attenuation	**C**	Barriers and noise panels on each side	86

6.6 Additional Costs

The costs also include the following:

- An allowance for project procurement costs, such as client project management, contractors' overheads, design costs, and profit (36%, has been used, as per other MS projects). It has only been applied to the construction costs.

- An amount or contingency to cover uncertainties related to the level of design detail and impact to the local neighbourhood. (50% has been used, in accordance with NAB, with respect to the level of detail of the study)

6.7 Overall Cost Estimates

The summary below includes the impact of all aspects combined. The chart shows the procurement costs and risk contingency included within each cost group.

Table 17:Construction Cost and Program Summary

Option		Description	Costs (M kr)					
			Construction Works	Expropriation	Maintenance (NPV)	Closure & Lost Revenue	Risk Contingency	Total
Heavy Cover	A	Full concrete cover	148	45	278	39	255	**765**
Light Cover	B	Steel frame	77	18	354	28	239	**716**
Barriers and Noise Attenuation	C	Barriers and noise panels on each side	28	9	107	3	73	**220**

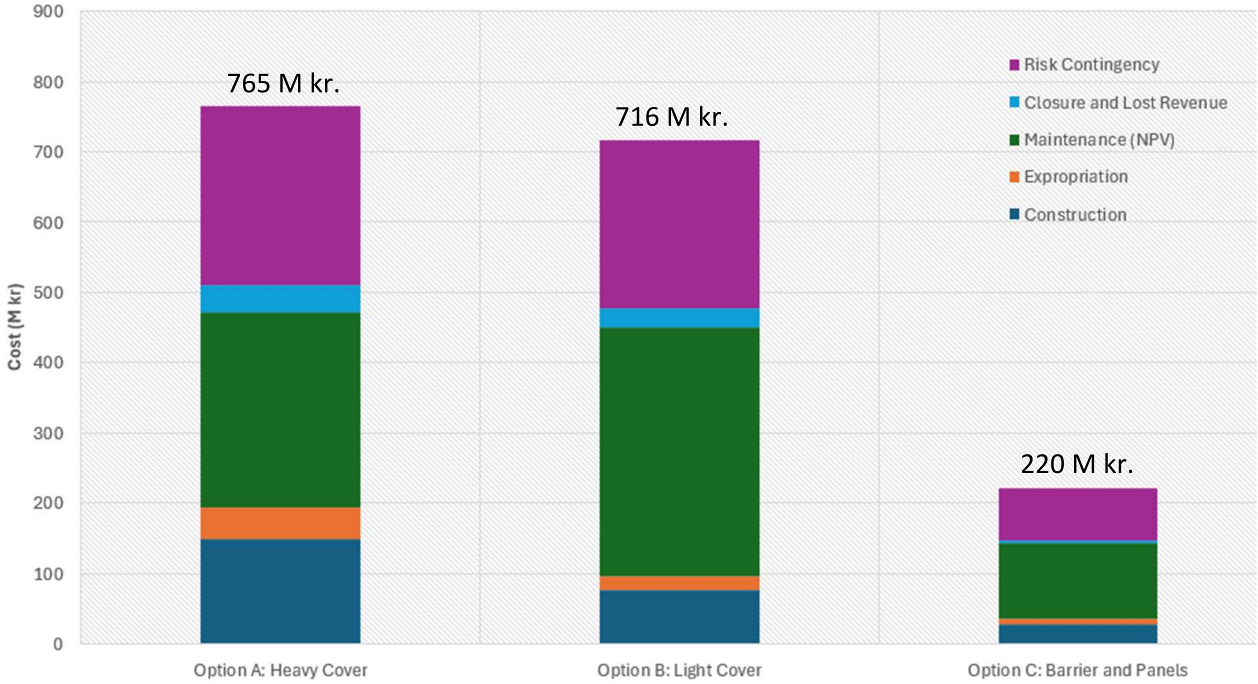


Figure 20: Construction Cost and Program Comparison Chart

7 Carbon Footprint

A calculation of the embodied carbon footprint has been undertaken to give an overview of the impact of each options.

The table below offers a high-level indication of the carbon footprint of each option over their 100 lifetime. It takes into account the supply of products from the factory to site (A1-A4), the construction work itself (A5) and also replacements of elements during its lifetime (B4), in accordance with the Life Cycle Assessment described in BS EN 15798.

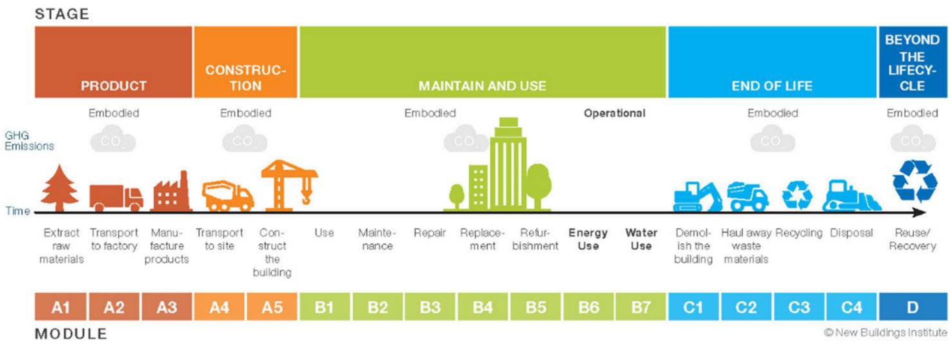


Figure 21 Project Life cycle Stages, according to BS EN 15798/2011

Table 18:Embedded Carbon Content Summary

Option		Description	Carbon (tonnes CO2e)				
			A1-3	A4	A5	B4	Total
Heavy Cover	A	Full concrete cover (240 m)	4,246	297	892	544	5,979
Light Cover	B	Steel frame (269 m)	1,224	86	257	1,567	3,134
Barriers & Noise Attenuation	C	Barriers and noise panels on each side	59	4	12	150	226

In summary, it can be seen that the carbon footprints of Option C and its variants are an order of magnitude smaller than those of Option A and B. The carbon footprint is a criteria that Metroselskabet is keen to take into account when determining a preferred solution.

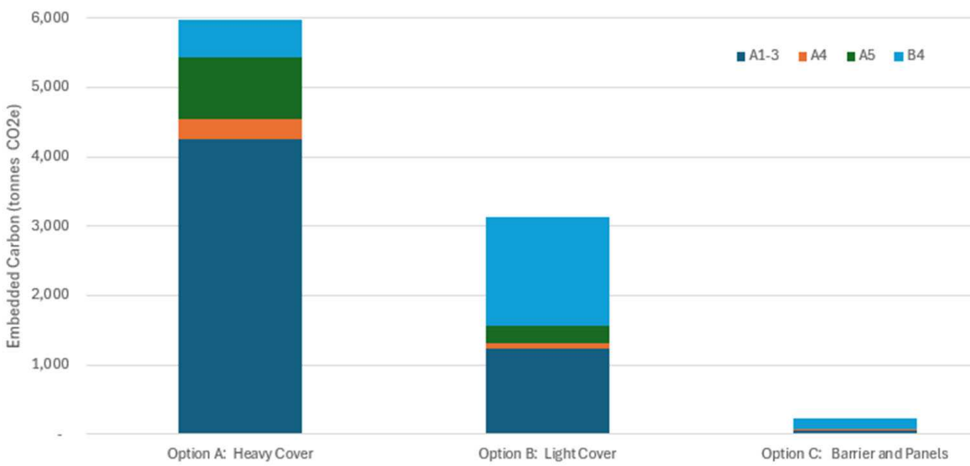


Figure 22:Embedded Carbon of Proposed Options

8 Appraisal of Options

The following chapter offers a comparison between the options presented, with a view to assist in taking a decision on taking any of the options forward for further design development. There are a great deal of unknowns at this stage that will need to be evaluated before a commitment to adopt any of the options.

Not withstanding this, Figures 26, 27,and 28 offer a comparison of the 3 base options, with respect to a number of criteria.

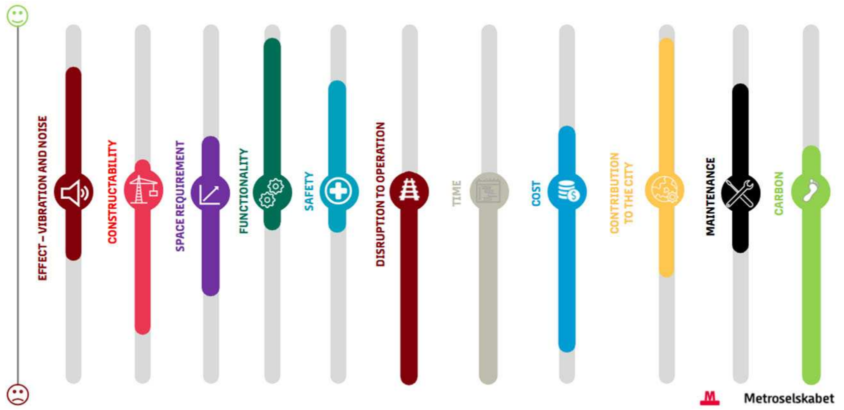


Figure 23: Option A:Heavy Concrete Cover: Appraisal Summary

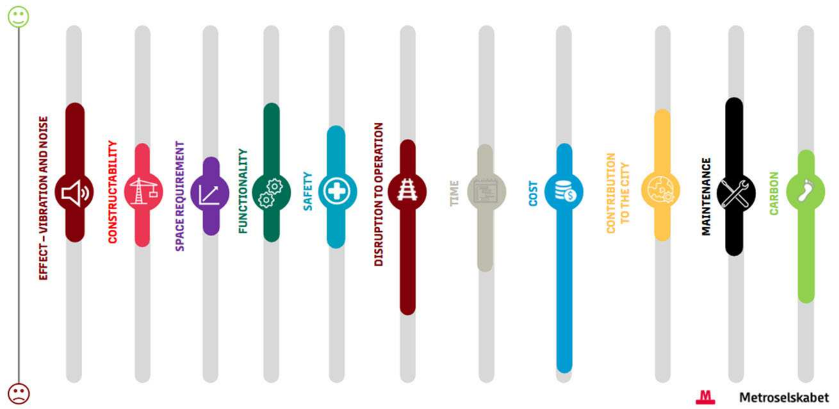


Figure 24: Option B Light Steel Cover: Appraisal Summary

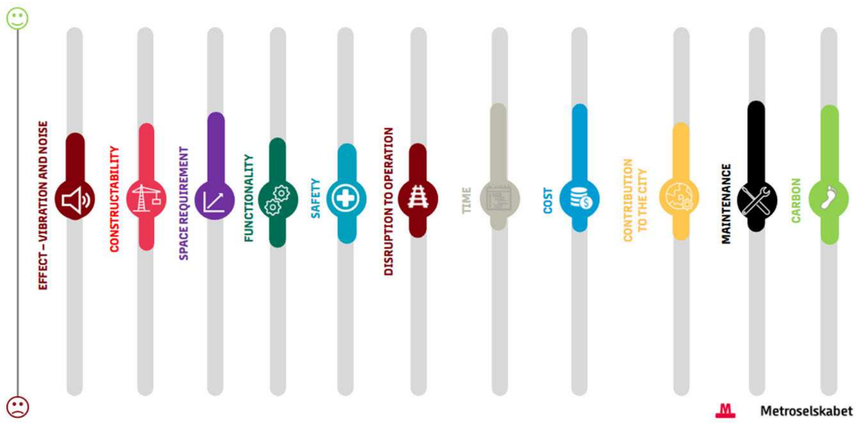


Figure 25: Option C Barriers and Panels: Appraisal Summary

8.1 Review of Option A: Heavy Cover

Table 19: Impacts of Option A

Functionality	Impact – Option A	
	Positive	**Negative**
Effect – vibration and noise	The cover acts as a physical barrier, preventing noise from escaping directly into the surrounding environment. Buildings near the covered section, and away from the exit/entrance are likely to experience significantly reduced noise from passing trains. With a cover in place, the reflection and dissipation of sound energy may reduce the intensity of vibrations in nearby structures, making the environment more stable and quieter. Concrete generally offers better sound insulation than steel. It is anticipated that the noise may be better contained with this heavy cover compared to the light cover.	The cover could act as an enclosure that amplifies certain frequencies, especially low-frequency sounds such as the rumbling of trains or vibrations, creating a "booming" effect nearby. Instead of being dissipated into the open air, sound waves might reflect off the cover's hard surfaces, concentrating noise around the tunnel entrance/exits and openings. The construction of the cover itself may generate temporary but significant noise that affects surrounding communities. This is expected to be higher than for the light cover option due to the deep foundation works.
Constructability	Due to the heavy weight of a precast slab solution, and the easement restrictions near the trough, it seems more appropriate to cast the slab *in-situ*. Additionally, the construction of the secant piles generates significantly more work than the light cover solution. Since the cover can be made of prefabricated steel components, most of the fabrication and assembly work can be done off-site. This reduces the need for prolonged on-site activities and minimizes the impact on train operations. As the cover is independent of the existing trough structure and relies on strip foundations a few meters away, there is minimal risk of destabilizing or damaging the trough during construction.	Due to the heavy weight of a precast slab solution and the easement restrictions near the trough, it seems more appropriate to cast the slab in situ. This approach implies building a formwork system inside the trough, which will need to be approved by Trafikstyrelsen. It also requires modifying the existing structure by cutting the sheet piles or secant piles, depending on the extent of the work. Additionally, deep foundations, as opposed to strip foundations, are typically slower and more costly to construct. They also pose a greater risk of damaging the existing sheet piles. Since the cover is dependent on the existing trough structure and relies on deep foundations placed a few meters away, there is a higher risk of destabilizing or damaging the trough during construction.

Functionality	Impact – Option A	
	Positive	**Negative**
	This simplifies the construction process and eliminates complicated interfaces with the existing infrastructure. Steel is lightweight compared to other materials like concrete, making it easier to lift, position, and assemble. Prefabricated steel parts can be transported and installed more efficiently using cranes during the brief construction windows, further limiting disruptions to metro operations. Strip foundations, as opposed to deeper or more complex footing types, are typically quicker and less costly to construct. and, can be performed without track closure.	This approach generates more complex and longer works while requiring more track closures compared to the light cover solution.
Space requirement	MS owns the area between the institution fence and retaining wall (approximately 2m wide corridor) in the south part Additional space created on top of the cover can be used for temporary storage during construction	Space would be needed in the north and south part of the trough for building the secant piles and do the modifications to the existing structure. The area between the retaining wall and the buildings is owned by Balder Øresund Strandpark ApS, necessitating temporary expropriation and relocation of the cycle path and light poles. Additionally, constructing the secant piles in the south part involves partial expropriation of the institution near the fence.
Functionality	The roof's main function is to act as a noise barrier. Similar to the light cover, it creates some additional space that can be used for even more functions and allow for potential development because of the higher load-bearing capacity.	Additional drainage along the trough needed to collect water from the roof.
Operational Safety	Safety is improved compared to the light cover because of a higher load-bearing capacity. Some vehicles may be able to drive on it as opposed to the light cover.	New risk related to the work from height for maintenance.
Disruption to operation	No benefits compared to options B and C could be identified.	The excavation of the foundations using piling equipment and lightweight equipment is not possible during metro operations, and would require a single-track closure during these works.

Functionality	Impact – Option A	
	Positive	**Negative**
		The modifications to the sheet piles would require full track closures, due the equipment required to be used within the trough. The casting of the concrete slab would require a series of full track closures. The initial set up for a formwork system would require an extended full track closure, and it is suggested that the pours also take place over a series of nightly full track closures. Expected track closure for maintenance works on the roof.
Time	No benefits compared to options B and C could be identified.	Longer design and construction period than the option B due to the use of deep foundations, the inability to use precast slabs, the partial demolition of the existing structure and the associated approval from the Authorities, and the reduced working hours due to limited track closures.
Cost	The cost could be offset by the potential development on top.	Construction cost in comparison to the light cover is higher because of the longer design and construction period, higher need of resources and the expensive disruption to operation. However, the maintenance cost is lower than for option B. Therefore, the total cost estimation over 100 years is lower than for option B.
Contribution to the city	Will limit noise pollution from Metro for the surrounding built environment and urban spaces. Will improve views for surrounding residences, depending on what the area will be used for in the future.	No clarity about future use of land (at this stage). Negative impact on the surroundings and for the metro passengers during the construction period.

Functionality	Impact – Option A	
	Positive	**Negative**
	Removes current barrier effect caused by the trough and allows for the planning of a coherent urban space, that can benefit both locals and visitors. Will potentially make room for more green space, and therefore also support biodiversity. Will not affect the possibility of developing the undeveloped plot south of the Metro's curved alignment. May reduce noise pollution so it enables the undeveloped plot south of the Metro's curved alignment to be utilised for e.g., residencies or offices, that will support the local neighbourhood and the Metro's customer base, rather than a parking garage. Has the potential to strengthen perceived safety as it allows for the planning of one coherent neighbourhood and/or urban space with no barrier effect. Total integration of Metro into the city and giving back urban space to the citizens.	
Maintenance	In comparison to Option B, less maintenance needed on the surface as the roof will be covered by some top soil, and the surface area maintained by KK.	Roof structure would need to be inspected regularly to check for potential damage. If a new ventilation system is installed, this would need to be maintained More dust expected leading to more cleaning
Carbon	Potential carbon offsetting due to the solar panels or the green roof on top.	Extensive use of concrete

8.2 Review of Option B: Light Cover

Table 20: Impacts of Option B

<table>
<tr><th rowspan="2">Functionality</th><th colspan="2">Impact – Option B</th></tr>
<tr><th>Positive</th><th>Negative</th></tr>
<tr><td>Effect – vibration and noise</td><td>The cover acts as a physical barrier, preventing noise from escaping directly into the surrounding environment. Buildings near the covered section, and away from the exit/entrance are likely to experience significantly reduced noise from passing trains.

With a cover in place, the reflection and dissipation of sound energy may reduce the intensity of vibrations in nearby structures, making the environment more stable and quieter.</td><td>The cover could act as an enclosure that amplifies certain frequencies, especially low-frequency sounds such as the rumbling of trains or vibrations, creating a "booming" effect nearby.

Instead of being dissipated into the open air, sound waves might reflect off the cover's hard surfaces, concentrating noise around the tunnel entrance/exits and openings.

The construction of the cover itself may generate temporary but significant noise that affects surrounding communities.</td></tr>
<tr><td>Constructability</td><td>Since the cover can be made of prefabricated steel components, most of the fabrication and assembly work can be done off-site. This reduces the need for prolonged on-site activities and minimizes the impact on train operations.

As the cover is independent of the existing trough structure and relies on strip foundations a few meters away, there is minimal risk of destabilizing or damaging the trough during construction. This simplifies the construction process and eliminates complicated interfaces with the existing infrastructure.

Steel is lightweight compared to other materials like concrete, making it easier to lift, position, and assemble. Prefabricated steel parts can be transported and installed more efficiently</td><td>Night time track closures significantly restrict working hours, limiting what the construction crew can achieve in one night. This may extend the overall construction timeline and increase costs due to prolonged mobilization and demobilization efforts each night.

Lifting and installing large sections of steel frames and roof covers will require large cranes, which need to be carefully positioned in a potentially constricted site.

Delivering and storing large steel spans near the construction site could pose logistical challenges, especially if space is limited. This may require careful planning to ensure components are delivered just in time for installation.</td></tr>
</table>

Functionality	Impact – Option B	
	Positive	**Negative**
	using cranes during the brief construction windows, further limiting disruptions to metro operations. Strip foundations, as opposed to deeper or more complex footing types, are typically quicker and less costly to construct. Preparatory works, such as strip foundations, can be performed without track closure.	Higher risk of damage to existing metro in case of lifting failure. Further development of the design in phase 2 would inform whether the current easement (20 kPa) allows for mobile crane without special measures (deep foundation for example)
Space requirement	MS owns the area between the institution fence and retaining wall (approximately 2m wide corridor) in the south part. Unlike the deep foundations needed for the concrete cover solution, strip foundations require less time for construction, and no piling rigs that would otherwise take up a lot of space.	Space would be needed temporarily in the north part of the trough for positioning the mobile crane. The area between the retaining wall and the buildings is owned by Balder Øresund Strandpark ApS. Temporary expropriation and relocation of the cycle path would be needed.
Functionality	The roof main function is to act as a noise barrier. It also creates some additional space that can be used for some functions that only require limited access for maintenance. Therefore, this has the potential to host some solar panels, or a green roof.	Additional drainage along the trough needed to collect water from the roof. This should be designed for storm surge event. Shorter design life than a heavy cover
Operational Safety	Due to the cover of the trough, safety is improved due a reduced risk for pedestrians or cyclists falling in the trough, and for objects to be thrown inside.	New risk related to the work from height for maintenance. Risk of falling equipment hanging from the roof
Disruption to operation	No expected track closure during the day	Single and full-track night closures are anticipated. Depending on the results of the fire-life safety study to be in phase 2, a temporary ventilation system and escape to the surface may need to be planned. Expected track closure for maintenance works on the roof
Time	Elements can be assembled during the day and installed at night. It is a repetitive sequence of work.	Longer design and construction period due to the relocation of utilities, construction of the drainage, the sealing work to close the gaps between the roof prefabricated elements, and the

Functionality	Impact – Option B	
	Positive	**Negative**
		potential additional works for solar panel installation or green roof.
Cost	Less material than option A, and no need to lower/cut the retaining walls to make space for the cover. No major modifications on the existing infrastructure as the structure is independent.	Construction cost in comparison to option C is higher because of the longer design and construction period, higher consumption of resources and the expensive disruption to operation. Also, the maintenance cost is higher than for option B. Therefore, the total cost estimation over 100 years appears higher than for option A and C.
Contribution to the city	Will limit noise pollution from Metro for the surrounding built environment and urban spaces. A green roof could help mitigate the *urban heat island* effect by reflecting less heat and absorbing more carbon dioxide compared to a traditional roof. It would also contribute to create more urban nature in the area. Views from the neighbouring apartments may be improved with the addition of a green roof, compared with conditions today and for this structure without a green roof, as neighbours 'look down' on metro infrastructure. Some green energy from the solar panels could be used for the future parking that may be developed south of the trough.	A light covering structure higher than the current upstand from the retaining walls will reinforce the barrier effect already created by the trough and may prevent the possibility of creating a coherent urban space. May negatively affect the possibility of developing the undeveloped plot south of the Metro's curved alignment depending on height and use of space. Has the potential to worsen perceived safety. A light covering structure will obstruct the undisrupted views from north of the trough towards the south and vice versa. The light covering structure has corners, which can create nooks that can feel unsafe. May have significant negative shadow impact on surrounding urban spaces, built environment and recreational outdoor space. May create glares that can affect surrounding built environment or traffic safety negatively depending on materials.

Functionality	Impact – Option B	
	Positive	Negative
		May be difficult to integrate into the current built environment and will potentially look out of place. May be subjected to vandalism like graffiti.
Maintenance	The infrastructure will be protected from the weather conditions, extending the durability of the equipment. Both solar panels and a green roof create a layer of insulation that helps regulate temperatures inside the trough. This could reduce heat buildup in the railway infrastructure and prevent freezing in winter.	Roof structure would need to be inspected to check for potential damages. If new ventilation system, this would need to be maintained. More dust expected leading to more cleaning.
Carbon	Limited use of concrete compared to option A . Potential carbon offsetting due to the solar panels or green roof on top.	More resources (material, machines) used compared to option C.

8.3 Review of Option C: Noise Barrier and Noise Attenuation System

Table 21: Impacts of Option C

Functionality	Impact – Option C	
	Positive	Negative
Effect – vibration and noise	Depending of the choice of noise barriers, it is assumed for this specific context that a reduction of up to 10 dB(A) can be achieved . Additional noise cladding in the trough can reduce the reverberation. It is not anticipated that the additional equipment creates any additional vibration.	Barriers alone may increase the reverberated noise inside the trough. Design should be considered to avoid this. Noise reduction for the apartments located on the upper floors may be less significant due to sound waves not caught by the noise barrier. This will have to be studied further in the Phase 2.
Constructability	Installation of the noise cladding and noise barriers can be done to a large extent from the surface at some locations, minimising track closures. Possible prefabrication at the surface Safer working environment than for the construction of a cover	Requires some night single track closures, but only at night. Affect the existing structure - Welding on the sheetpiles/ drilling in the retaining wall. Potential risk of the noise barrier falling in the trough during the operation.
Space requirement	Requires less space at the surface compared to a prefabricated or cast in cover. Fewer plant and equipment needed.	
Functionality	Noise reduction. Potential for green walls. Potential for solar energy walls.	No additional useable space created above the trough. Shorter design life than a heavy cover.
Operational Safety	Improved safety with a reduce risk for pedestrians or cyclists of falling in the trough.	Work from height to install noise cladding inside the trough

<table>
<tr><th rowspan="2">Functionality</th><th colspan="2">Impact – Option C</th></tr>
<tr><th>Positive</th><th>Negative</th></tr>
<tr><td></td><td></td><td>Potential risk of the noise barrier falling in the trough during the operation in case of fixation failure</td></tr>
<tr><td>Disruption to operation</td><td>No impact on the existing safety approval of the system.</td><td>Single track night closure</td></tr>
<tr><td>Time</td><td>Shorter design and construction period
Elements can be assembled during the day and installed at night in a systematic way</td><td>Slower process due to the short time available during a night single track closure (3h)</td></tr>
<tr><td>Cost</td><td>Shorter design and construction period
Less material than for a cover
No major modifications on the existing infrastructure</td><td>Final cost will be impacted by the material specification for the different noise barriers options defined in phase 2</td></tr>
<tr><td>Contribution to the city</td><td>Will limit noise pollution from Metro to the surrounding built environment and urban spaces.

The walls have the potential to enforce a local sense of place if used e.g., for artwork, but can also support biodiversity and microclimate if covered in greenery.

Walls will have less to no impact on the possibility of developing the undeveloped plot south of the Metro’s curved alignment.

May reduce noise pollution so it enables the undeveloped plot south of the Metro’s curved alignment to be utilised for e.g., residencies or offices, that will support the local neighbourhood and the Metro’s customer base, rather than a parking garage.

May not significantly affect the existing urban environment, and will be relatively easy to integrate.</td><td>Will reinforce the barrier effect already created by the trough and will prevent the possibility of creating a coherent urban space.

Has the potential to worsen perceived safety. Walls will disrupt the current undisrupted views from north of the trough towards south and vice versa.

Potentially have negative shadow impact on surrounding urban space, built environment and outdoor recreational space for residencies and institutions.

May be subjected to vandalism like graffiti.</td></tr>
<tr><td>Maintenance</td><td>No need to maintain new ventilation system due to a cover</td><td>Restricted access behind the noise cladding for potential maintenance</td></tr>
</table>

Functionality	Impact – Option C	
	Positive	**Negative**
	Minimal change in the maintenance regime of the existing infrastructure	Potential graffiti removal or trimming of the green fence
Carbon	Limited use of concrete Less resources (material, machines) used compared to a cover solution	Not carbon neutral

9 Summary and Conclusions

9.1 Summary of Appraisal

Overall summary of options is shown below, using similar scoring criteria as used on other evaluations undertaken with København Kommune for future metro projects.

Table 22: Option Comparison Summary

Option Variant	Heavy Cover A	Light Cover B	Barriers/ Panels C
Noise Impact (During Construction)	E	D	B
Noise Reduction (Permanent)	B	B	C
Constructability	E	C	B
Access and Landtake	D	C	B
Functionality	A	B	C
Safety	B	C	C
Disruption to Operation	E	D	B
Construction Program	E	D	B
Construction Cost	E	D	B
Contribution to the City	A	B	B
Maintenance	B	C	B
Carbon	E	E	A

The table below provides a comparison of the early assessment of expected noise reduction that could potentially be achieved by the different methods. Note that Option A would need to be supplemented by a short section using Option B or C to provide full coverage, due to the secant piles located near the portal.

Table 23: Noise Comparison Summary

Option	Method	Noise Reduction
Option A:	Concrete cover	Up to 20 dB(A)
Option B:	Steel frame, steel facade, supplementary noise attenuation panels	Up to 15 dB(A)
Option C:	Barriers and Noise attenuation Panels	Up to 10 dB(A)

9.2 Recommended Option

This study presents three conceptual designs, with variations. At this early stage, there are a great number of unknown aspects that would need to contribute to the functional design and the practical aspects of construction that need further elaboration.

Perhaps the two greatest concerns are:

- How can any works be constructed around a live metro system? The impact of closures is significant, and any closures must be agreed with the operating company. At this stage, assumptions have been made as to what closures would be required, but it is essential that this aspect be looked into with greater focus, to ensure that the required closures are feasible.

- The solution must meet the function requirements. At this stage, no functional requirements on noise reduction have been established. We are still to ascertain the following:

    - The source of noise that is unwanted

    - The volume of noise currently emitted by the metro system

    - The limit of the volume that should be targeted by noise reduction measures.

Taking into account what we know at this stage, and based on the overall assessment, and taking account of the cost and program impact, **the solution preferred by MS is Option C.**

This option offers minimum disruption, it is the cheapest option by a significant margin, and offers a high level of benefit to the local residents and stakeholders. Benefits include:

- The impact on the existing metro assets are kept to a minimum with Option C.
  Option A requires some significant modifications to the existing sheet piled retaining structure, and while this is considered feasible, it is a risky procedure, and gives concern about safety approval, which may cause unexpected delay to not only the project, but to the numerous track closures that are required.

- There is minimal impact regarding easements or expropriation at the boundary to the institutions with Option C.
  Both options A and B require temporary land expropriation of the nearby educational institution. The secondary impact this will have has not been included in the analysis.

- The work can be done with the fewest track possessions – and without any double track closures. Option A and B both require an unprecedented number of double-track closures. Track closures not only cost money to facilitate, and lose money due to loss of revenue, but also cause long-term behavioural changes that can last months. They also cause reputational damage than can last even longer.

- The extent of the project could be staged, such that parts are built soon, and the extent is increased at a later date.

The choice of the extent of the option along the length of the trough is subject to further analysis. The Phase 2 studies are intended to develop the option to ensure it performs to meet the expectations.

Furthermore, it is recommended that the supplementary options of green walls be investigated further.

9.3 Next steps in Phase 2

The following next steps are considered essential in the development of an option that performs as intended, and meets the stakeholder requirements as best as possible:

- Agree on a preferred solution to develop further; and
- Agree how to engage with Teknik og Miljøforvaltningen (TMF) as we developed the project further.

KK and MS shall agree which option or options to develop further. Depending which option is selected, it will require different next steps to be taken.

Following this critical decision, the following studies are required:

1. Noise Study Analysis

Before any system that offers a reduced impact of noise to local receptors can be designed, it is essential to better understand the noise, specifically:

- what are the noise emitters in the metro system;
- what is pitch frequency (Hz) of the noise in question;
- what is the volume range. It is also critical to better understand the source of the noise, and its location within the trough; and
- What is an acceptable volume to target in proposed noise reduction measures.

This will allow the barrier and the attenuation system to be specified accordingly, to bring the most benefit with the best economy.

2. Green Wall/Green Roof Study

The use of green walls shall be investigated with specific consideration of the following:

- Quantifiable improvement to urban nature
- Aesthetics
- Durability and Maintenance
- Acoustic performance

3. Rail Safety Review

An assessment of the impact of the works on the rail safety approval is essential, especially as the system has been approved in relation to legislation, that may be obsolete for the current change. We must make sure all necessary steps are taken in the design development to ensure that the metro system can remain operational (including in periods of reduced operation).

A discussion and agreement with the O&M provider and the NSA is required, to ascertain which relevant approvals shall be in place before, under and after the change has been implemented.

4. Constructability Assessment

An assessment of the critical limitations for the planned structural works needs to be assessed, to allow for a more accurate estimation of methods, time schedule and associated costs. This is particularly critical with regard to Option A, which requires modification to the load-bearing sheet pile retaining walls.

5. Closure Strategy

All options require some track closures in order to construct the works. For some options, repeated periods of double track possession are required, leading to extraordinarily long construction programmes. For comparative purposes, this may be useful, but in reality, some optimisation and coordination of the works together with other closures may be possible.

Ultimately, any work on metro system that require closures must be discussed and agreed with the Operator, and therefore next steps should include early involvement with the Operator to confirm that the closure proposals are realistic.

6. Easements and Expropriation Study

The cost and the viability of expropriation easements have not been considered. Initial estimates suggest that an area of 6000m^2 would be required for the worksite for all options. A further study considering the extent and cost of work with respect to the areas and rights protocols is required.

7. Tunnel Ventilation Study

If option A or B is selected, then a study to determine the ventilation requirements of the options, to determine if either ventilation openings are required, or if forced ventilation is necessary under new parts of the cover.

A 1-D analysis would confirm if the existing tunnel ventilation can be used or it would require assistance from some new jet fans installed below the covers. If the project proposes to have ventilation openings in the cover, a CFD analysis should be carried out to confirm size, location and number of openings.

8. Cost and Program Update

Following selection of the preferred option or options, cost and programme key considerations can be identified and communicated with the design team. As design progresses the cost estimate and schedule can be refined to ensure transparency for stakeholders and, where necessary, challenging design parameters to ensure cost and programme efficiency.

At pre-agreed junctures, the cost estimate and programme will be updated in greater detail reflecting the most current and more specific design and can be tied into the design stage approval's process ensuring stakeholders are always fully in control of schedule and budget.

As detail increases – the degree of precision on cost and schedule will follow providing increasing certainty, with the potential for reducing budgetary contingencies, encouraging efficiency in design and planning at each stage.

9.4 Future Studies after Phase 2

Further work beyond this study may include auxiliary construction works that might offer revenue streams to help fund these works. This is applicable to Option A which would allow the construction of a variety of low-rise surface structures to be placed on top, which may help fund the works. This could include:

- Retail buildings, such as food outlets or cafes;
- Public amenities, such as sports or fitness centres;
- Car parking and charging facilities; and
- Solar energy collection systems.

All these items would require consideration by KK to determine appetite for such suggestions.