

## Allélänken

A study of the possibility and the potential effects of a tramway tunnel construction in Gothenburg city

*Master of Science Thesis in the Master's Programme Geo and Water Engineering*

MARTIN RUDOLPHI

Department of Civil and Environmental Engineering  
Division of GeoEngineering  
Road and Traffic Group  
CHALMERS UNIVERSITY OF TECHNOLOGY  
Göteborg, Sweden 2012  
Master's Thesis 2012:11



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Chalmers tekniska högskola 2012:11

Department of Civil and Environmental Engineering

Division of GeoEngineering

Road and Traffic Group

Chalmers University of Technology

SE-412 96 Göteborg

Sweden

Telephone: + 46 (0)31-772 1000

Cover:

An excerpt of the proposed tramway design near Gothenburg central train station.

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## ABSTRACT

The Gothenburg tram network is Scandinavia's largest with its 160 kilometers of tracks and just over 100 million trips each year. The central parts of the network offer today low average speeds and the majority of tram lines pass through the often heavily congested hub Brunnsparken. This thesis studies the prerequisites and the potential effects of constructing a centrally located tramway tunnel in Gothenburg that could increase the capacity of the network and unburden Brunnsparken. Methods used in the study have been literature study, correspondence with people within the field and also the execution of a track design for the tunnel.

The central parts of the city is founded on deep layers of clay, why tunneling in these parts often becomes very structurally difficult and expensive. The area along the avenue Nya Allén is undeveloped which could enable a tunnel construction without these structural difficulties or major costs. The proposed design connects to existing light rails at Polhemsplatsen and Linnéplatsen and includes four stations: Centralstationen, Avenyn, Haga and Järntorget. The stations locations correspond well to the plans in the public transportation program for Gothenburg and the stations are designed with a length of 110 meters to meet future needs.

The total cost for Allélänken is estimated to 3,5±1 billion SEK and the travel time between Polhemsplatsen and Linnéplatsen is reduced from today's 16 to 6 minutes. No significant impacts on existing buildings are expected along the route, but major environmental impacts will be required particularly along Nya Allén. When utilizing the maximum capacity of the tunnel, about 44 percent of the total tram traffic can operate in the tunnel by 2030. Tram lines 1, 7, 9 and 11 constitute 40 percent of the total tram traffic. If these lines operate in the tunnel the loading rate of Brunnsparken will in 2030 be lower than in today's situation, given that Operalänken is completed. Future extension possibilities of Allélänken can be implemented according to the plans in K2020, with extensions to Masthugget, Lindholmen and Korsvägen.

Key words: Allélänken, Brunnsparken, Gothenburg, infrastructure, K2020, light rail, public transportation, Stadtbahn, tram, tramway, tunnel, Västlänken

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Grupp Väg och Trafik

Chalmers tekniska högskola

## SAMMANFATTNING

Göteborgs spårvägsnät är Skandinaviens största med 160 kilometer spårväg och drygt 100 miljoner resor per år. De centrala delarna av nätverket har idag låga medelhastigheter och merparten av spårvagnslinjerna passerar genom det ofta överbelastade navet Brunnsparken. Detta examensarbete undersöker förutsättningarna och dem möjliga effekterna av att bygga en centralt belägen spårvägstunnel i Göteborg som skulle kunna öka kapaciteten i nätverket och avlasta Brunnsparken. Metoderna som har använts i studien är litteraturstudie, korrespondens med personer inom branschen och även utförandet av en spårprojektering för tunneln.

De centrala delarna av staden är byggda ovanpå djupa lerlager, vilket gör att tunnelbyggnation i dessa delar ofta blir väldigt byggnadstekniskt svårt och kostsamt. Området längs Nya Allén är inte bebyggt vilket möjliggör en tunnelkonstruktion utan dessa stora byggnadstekniska svårigheter eller stora kostnader. Den föreslagna utformningen ansluter till befintlig snabbspårväg vid Polhemsplatsen och Linnéplatsen samt inkluderar fyra stationer: Centralstationen, Avenyn, Haga och Järntorget. Stationslägena stämmer väl överens med planerna i kollektivtrafikprogrammet för Göteborg och stationslängderna är 110 meter för att tillgodose framtida behov.

Kostnaden för Allélänken är uppskattad till  $3,5 \pm 1$  miljarder SEK och restiden mellan Polhemsplatsen och Linnéplatsen reduceras från dagens 16 till 6 minuter. Ingen betydande påverkan förväntas av befintliga byggnader men stor miljöpåverkan kommer att ske särskilt längs Nya Allén. När maximal kapacitet utnyttjas i tunneln så kan cirka 44 procent av den totala spårvagnstrafiken trafikera tunneln år 2030. Spårvagnslinjerna 1, 7, 9 och 11 utgör 40 procent av den totala spårvagnstrafiken. Om dessa linjer trafikerar tunneln så kan belastningsgraden i Brunnsparken år 2030 bli lägre än i dagens situation, under förutsättning att Operalänken är byggd. Framtida utbyggnadsmöjligheter för Allélänken kan ske i linje med planerna i K2020, med utbyggnad mot Masthugget, Lindholmen och Korsvägen.

Nyckelord: Allélänken, Brunnsparken, Göteborg, infrastruktur, kollektivtrafik, K2020, snabbspårväg, spårvagn, Stadtbahn, spårväg, tunnel, Västlänken

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## Preface

This Master of Science thesis has been carried out between February and June 2012 at the division of GeoEngineering, Road and Traffic Group, Chalmers University of Technology, Sweden. The project has been performed at Ramböll in Gothenburg, Sweden.

There are several people who have helped me during the writing of this thesis to whom I would like to express my deepest gratitude. First and foremost I want to thank my supervisor Patrik Sterky at Ramböll who is the creator of the idea for the thesis and who has been supporting and an inspiration throughout the entire project. Other people at Ramböll I would like to thank are Karin Wahlberg for having an enormous patience with my InRail questions, Per Åkesson for providing me with an office space and the rest of the Road and Railway division at Ramböll for your welcome.

I would also like to thank the staff at GS Spårvagn, Trafikkontoret and Stadsbyggnadskontoret in Gothenburg and also Cedric Hanneberg and Carl Silfverhielm at Ramböll Stockholm. Thank you also Ulf Nyström at Göteborgs-Posten for your article about Allélänken and the participants in the Ramböll tunnel group for your help.

Last but not least I would also like to thank my supervisor and examiner at Chalmers Gunnar Lannér for your time and knowledge and also my opponent André Norberg for a job well done.

Gothenburg, June 2012

A handwritten signature in black ink, appearing to read 'Martin Rudolphi', written in a cursive style.

Martin Rudolphi

# Glossary

## English

Detailed development plan  
Gothenburg  
The Gothenburg region  
The Gothenburg tram network  
The Göta tunnel  
Grade separation  
Horizontal alignment  
Flyover  
Light rail  
Loading rate  
Moat  
Municipality  
The Public Transport Authority  
Region Västra Götaland  
Reserved track  
The Swedish Transport Administration  
Tram  
Tramway  
Tunnelling  
The West link  
The West Swedish solution

## Svenska

Detaljplan  
Göteborg  
Göteborgsregionen  
Göteborgs spårvägsnät  
Götatunneln  
Planskildhet  
Horisontell linjeföring  
Viadukt  
Snabbspårväg  
Belastningsgrad  
Vallgrav  
Kommun  
Trafikkontoret  
Västra Götalandsregionen  
Särskild banvall  
Trafikverket  
Spårvagn  
Spårväg  
Tunnelbyggnation  
Västlänken  
Västsvenska paketet

## Map of central Gothenburg

This thesis focuses mainly on the central parts of Gothenburg. Several locations in the city are thus referred to in the text. The map in Figure I is meant to help the reader to locate these locations. The map is generated in Google Maps (2012 (edited)).



Figure I 1-Folkkungabroarna, 2-The old moat, 3-Linnéplatsen, 4-Järntorget, 5-Lilla torget, 6-Göteborg centralstation, 7-Fattighusån, 8-Polhemsplatsen, 9-Brunnsparken, 10-Hagakyrkan, 11-Göta älv, 12-Kungssportsavenyen, 13-Hagabion, 14- Kungsparken, 15-Drottningtorget





# 1 Introduction

The Gothenburg tram network is Scandinavia's largest with its 160 kilometers of tracks and just over 100 million trips each year (Göteborgs Spårvägar, 2009). The network is a combination of street running tracks centrally and outer parts which mainly consist of reserved tracks, often referred to as light rail. The tracks in the central tram network share to a large part lanes with buses and cars, whereas the outer reserved tracks mostly are separated from other traffic. These prerequisites result in large differences in standards with average speeds of about 10 km/h centrally and up to 40 km/h in the outer parts (Eniro & Västtrafik).

The most frequented hub in the network is Brunnsparcken where 10 out of totally 12 tramlines pass through at a frequency of 9-10 minutes during peak hours (Västtrafik, 2012). Brunnsparcken is today frequented beyond its practical capacity<sup>1</sup>, which inevitably often leads to congestion in the area with long travel times through central Gothenburg as a result.

Investigations have been made in the past, both in 1934 and 1967, on a conversion of the central tram network into an underground subway network (Sveriges Radio, 2009). The investigation from 1967, called *Stadsbaneutredningen*, resulted in the construction of many of the light rail sections today found in the outer parts of the network. The central underground network was however never realized due to a lack of money or willing power, or a combination of the two (Trivector Traffic, 2012). The difficult geotechnical prerequisites in central Gothenburg, with clay extending as deep as 100 meters (Stadsbyggnadskontoret, 2010), most probably also played a major part in the abandonment.

A large increase of trips made with the public transportation in the Gothenburg region is a goal stated in the public transportation program by GR et al. (2009). The market share for the public transportation is planned to increase from today's 24 to 40 percent by the year 2025. In addition to this the railway tunnel Västlänken, which is planned to open in 2028, will give commuters an increased accessibility to the city with regional growth as a result (Trafikverket, 2011). With an increased demand of local public transportation trips as a result of this, the need of new long-term solutions for mainly the central part of the Gothenburg public transportation network is apparent.

Grade separation between the different modes of transport in a city is a prerequisite in order to provide fast public transports with a high capacity. A tunnel solution in the most central parts in Gothenburg has proven to be hard to implement because of the soft clay and the buildings founded on it. A centrally located area in the city that has not been developed is the park area along the avenue Nya Allén. The area, in combination with an extension in Linnéstaden, provides good prerequisites for constructing a centrally located tramway tunnel that could connect the outer light rail sections at Polhemsplatsen and Linnéplatsen. In this way a consistent grade separated tramway can be created between the districts Angered/Bergsjön and Tynnered and an unburdening of the heavily loaded Brunnsparcken can be achieved.

---

<sup>1</sup> Kent Lindahl (Head of planning, GS Spårvagn AB) e-mail 2012-03-13

## **1.1 Purpose**

The purpose of this Master's thesis was to study the prerequisites and the possibility of constructing a tramway tunnel between Polhemsplatsen and Linnéplatsen in Gothenburg, connecting existing light rail sections from Angered/Bergsjön and Tynnered. The purpose was also to suggest a design for the tunnel and to study the potential generated effects and analyze these from appropriate aspects.

## **1.2 Delimitations**

The purpose of this thesis offers a wide range of possible areas to investigate and analyze. The properties described and the effects analyzed in the thesis have by the author been considered to be the most important ones to include for providing the reader with the most relevant information. Simulation of the traffic, temporary arrangements during construction and socio-economic valuation are examples of possible studies that have been excluded due to the thesis' limited format.

Certain chapters in the thesis are brief relative to their actual significance. This applies primarily to the Chapters 5.4 concerning the construction details of the tunnel and 6.1 concerning the estimated costs of the project. In these chapters the lack of data has significantly limited the extent of the studied areas. Given the mentioned prerequisites, this Master's thesis should hence not be considered as an actual investigation of the proposal but rather as an initial study.

## **1.3 Method**

### **1.3.1 Literature study**

Literature study is the method used mainly in the first four chapters of the thesis, but also to some extent in the later chapters. Emphasis has been placed on reports concerning the Västlänken project as these have contained much relevant information about Gothenburg from a tunneling perspective. These reports as well as the other sources have mainly been accessed online.

### **1.3.2 Interviews**

Information has been gathered from appropriate people with knowledge within the field. Correspondence has been made via e-mail, telephone and meetings to get answers to questions regarding the work of the thesis. Contact has been made internally within Ramböll as well as externally to other companies and authorities.

### **1.3.3 Design**

A track design for the proposed route has been made in the software Bentley Microstation and Bentley Rail Track. This has primarily been done to investigate the possibility of constructing a tramway tunnel in the existing city structure in Gothenburg between Polhemsplatsen and Linnéplatsen. The design provided valuable information on areas affected, critical parts along the route, appropriate track geometry among other things. The track design is found in Appendix VI.

The tunnel sections presented in Chapter 5.4.3 are designed in the software AutoCAD. The digital map of Gothenburg used in the track design has been acquired by Stadsbyggnadskontoret (2012). Design criteria for the tracks have been acquired from AB Stockholms lokaltrafik (2009).

### **1.3.4 Interim presentations**

During the writing of this thesis, the proposal of Allélänken has been presented together with supervisor Patrik Sterky at three different occasions. Initiatives for the presentations have been made from both the supervisor and stakeholders.

The first presentation was made March 28<sup>th</sup> at Göteborg City Hall for Johan Nyhus, chairman of the traffic committee. The meeting provided an opportunity of presenting the proposal to an influential politician and also provided valuable feedback.

The second presentation was held for an internationally assembled tunnel group within Ramböll, at Ramböll's office in Gothenburg April 20<sup>th</sup>. After the presentation the design of the tunnel was discussed and the participants made a cost estimation for the project.

The third presentation was made during a meeting with Ulf Nyström, journalist at the newspaper Göteborgs-Posten. The meeting resulted in the publication of an article about Allélänken in Göteborgs-Posten June 4<sup>th</sup>, which is found in Appendix V. Some comments on the project, published June 5<sup>th</sup> in Göteborgs-Posten, are also found in this appendix.

## 2 Public transportation projects in Gothenburg

This chapter gives an overview of some important historical, planned and on-going public transportation projects in Gothenburg.

### 2.1 Subway investigations

Investigations have previously been made on an extensive underground public transportation system in Gothenburg. The first known investigation was presented in 1934 and showed the suitability of a subway based on the city's steadily increasing population. The director of Gothenburg's tramway, C A Reuterswärd, made along with his colleagues the investigation where the central part of the network design is showed on the left in Figure 2.1. Calculations showed that the project would be profitable already after a few years, but for unknown reasons the investigation was never presented to the politicians of Gothenburg (Sveriges Radio, 2009).

More than three decades later in 1967, another subway investigation was made. It was called *Stadsbaneutredningen* and suggested that the tram network in Gothenburg should be replaced with a subway (one of several central designs showed to the right in Figure 2.1). The network would also extend out to the newly built suburbs on reserved tracks, mostly running over ground without level crossings (Lenngren & Schwandl, 2009). This kind of network structure was at the time widely developing in many German cities and passed under the name of *Stadtbahn*.



Figure 2.1 Extracts from subway investigation maps from 1934 and 1967 (Sveriges Radio, 2009).

At the end of the 1960's, a governmental subvention was assigned for the development of Stockholm's subway (Ohlsson, 2007). The condition needed for Gothenburg to receive an equal financial share was that the development of the network maintained an equivalent standard to Stockholm's subway. This condition played a major role in the large investments made in light rail sections to the suburban areas. The central subway system in Gothenburg never became a reality due to a lack of money or willing power, or a combination of the two (Trivector Traffic, 2012). The extensions to the suburbs were however built and have since provided fast tramway connections on mostly reserved track to Angered, Bergsjön and other suburban areas.

## 2.2 Kringen

Kringen is short for *Kollektivtrafikringen* (the Public transportation ring) and is an ongoing tramway project in Gothenburg in three phases. The project originated from an abandoned idea of an Automated Guideway Transit (AGT) that was planned as a ring around the city. In the vacuum created from the abandonment of AGT the Kringen project was born as a way of translate the principles from AGT into tramway (Bernmar, 2007). The aim of the Kringen project is to offer an alternative fast route around the city center and thereby unburden the sometimes chaotic Brunnsparcken and Centralstationen (Trivector Traffic, 2012).

The first phase of the project included new tracks between Folkungabroarna and Korsvägen, the tunnel *Chalmerstunneln* between Korsvägen and Chalmers and a bridge between the hospital Sahlgrenska and Linnéplatsen called *Annedalsmotet*. Annedalsmotet and Chalmerstunneln were opened in 2002 and the tracks between Folkungabroarna and Korsvägen were opened in 2003 (Trafikkontoret, 2006).

The second phase, *Spårväg Skeppsbron*, has been designed but has not yet been constructed. This phase stretches between Skeppsbron and Lilla torget and is planned to be finished and operating in 2015 (Älvstranden utveckling, 2012). The extent of the third and last stage of the project has not yet been determined, but will most likely involve an extension of the second phase to the Göteborg opera and Drottningtorget, called *Operalänken*. A sketch by Trafikkontoret of the two first phases of Kringen is shown in Figure 2.2 (Bernmar, 2007).

The project is a part of *Göteborgsöverenskommelsen* where Götatunneln and the purchase of the new M32 trams among other things also are a part (Trafikkontoret, 2006). Kringen will not function as a beltway per se, but is rather used by existing lines that operate on appropriate sections to produce the highest benefit to the maximum numbers of travellers (Trivector Traffic, 2012).

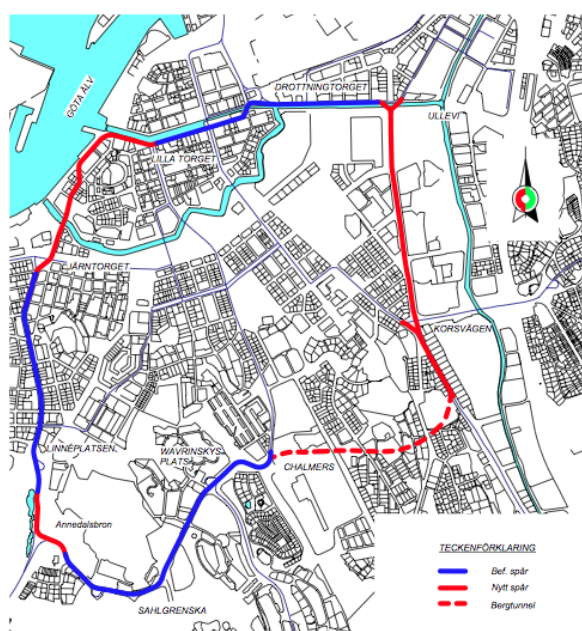


Figure 2.2 Design of the Kringen project. Blue lines show existing tracks and red show the new tracks included in the two first phases of the project.



## 2.3 Västlänken

The Swedish government presented in 2010 a national plan for Sweden's transportation system 2010-2021. The plan involves investments of 482 billion SEK on infrastructure projects in Sweden between 2010 and 2021 (Näringsdepartementet, 2010). *Västsvenska paketet* (the West Swedish solution) is one part of the national plan and includes infrastructure investments of 34 billion SEK (Trafikverket, 2012). The solution constitutes several projects and the majority of them are situated in Gothenburg.

The single largest project in the solution is *Västlänken* (the West link) that has an estimated cost of 20 billion SEK. Västlänken is a six kilometers long double-track railway tunnel passing under the central of Gothenburg with three centrally located through stations; Göteborg C, Haga and Korsvägen as seen in Figure 2.3. Haga and Korsvägen will be built with two tracks, but are designed for future capacity of four tracks. Göteborg C will already from the start be built with four tracks (Banverket et al., 2006f).

The current terminus central station is today operating at its maximum with 370 trains per day (Banverket et al., 2006b). The new stations will increase the accessibility to the city and also the passenger capacity significantly (Trafikverket, 2012). The current station will remain but will most likely be reduced from today's 16 tracks and handle less trains since the majority of trains instead will be operating on Västlänken.

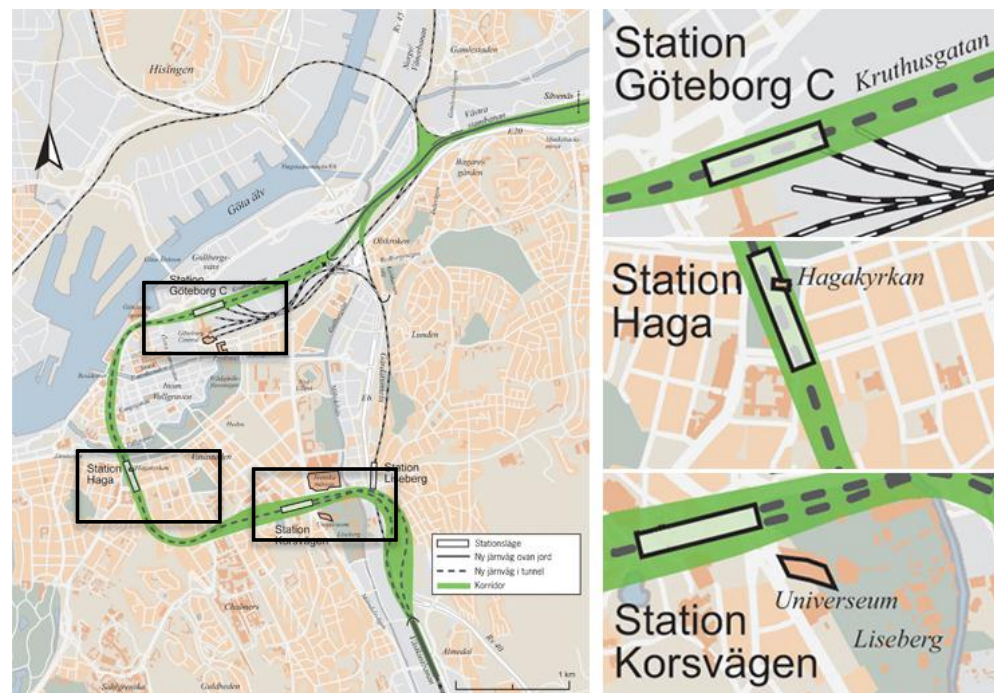


Figure 2.3 Västlänken and its stations (Trafikverket, 2012 (edited))

By creating faster transport possibilities with a high capacity, commuting to Gothenburg will be more attractive with regional and economic growth as a result (Trafikverket, 2011). In the background report *Trafikering och reseanalys* by Banverket et al. (2006a), the increase in regional and long-distance public transportation as a result of Västlänken is expected to be 15 percent compared to the

null alternative (the alternative of doing no investment). This generates 126 000 regional and long distance public transportation trips per day, departing or arriving within the Gothenburg area, which can be compared to 110 000 for the null alternative and 52 000 trips which was made in 2006. With two additional train stations, Haga and Korsvägen, more commuters will be able to reach their start or final destination by foot. The report states however that the local public transportation (trams, buses and boats) still will be used by 52 percent of the passengers departing or arriving at station Haga and 76 percent at station Korsvägen.

The tunnel will be constructed in both rock and clay why varying tunneling techniques thus are required. The techniques that are planned for excavations are *cut-and-cover* in soil and the conventional *drill and blast* in rock (Banverket et al., 2006c). Because of the inevitable intersection between Västlänken and the Göta tunnel, reinforcements of the Göta tunnel's roof were made in its eastern part. The additional cost for the reinforcement amounted to about 5 million SEK<sup>2</sup>.

## 2.4 K2020

K2020 is a collaborative project between different organizations involved in public transportation issues in *Västra Götalandsregionen* (Region Västra Götaland). The project was launched in 2004 in order to create opportunities for a continuing growth and a sustainable development in the Gothenburg region (Karlsson & Larsson, 2010). The aim of the project is to increase the market share for public transportation in the Gothenburg region from 24 to 40 percent at latest in 2025. The project also aims at creating a collective future scenario to be used as a base for future planning and decision-making in public transportation in the Gothenburg region (GR et al., 2008).

The collective vision is a growing Gothenburg region and a crucial prerequisite for this is an increased share of trips made by public transportation. The expected increase translated into numbers means 900 000 trips per day totally in public transportation in the Gothenburg region compared to 400 000 trips made in 2006 (Banverket et al., 2006a).

The vision for the Gothenburg tram network is to extend the present beltway Kringen with connections to Norra älvstranden. The vision is called *Storkringen* and is showed left in Figure 2.4, where also the planned future bus network is shown to the right.

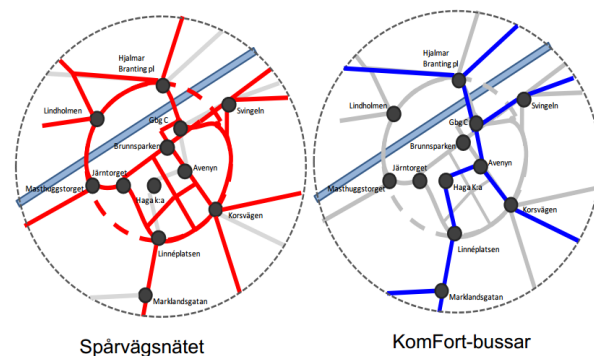


Figure 2.4 Vision for Gothenburg's tram and bus network from K2020 (GR et al., 2009)

<sup>2</sup> Anonymous source (Project leader, Västlänken) interview 2012-03-05

### 3 The Gothenburg tram network

The Gothenburg tram network was established in 1879 and consisted originally of a narrow-track horse-drawn tram. The system was electrified in 1902 and was at the same time converted to standard gauge track. The first electrified lines originated from Brunnsparcken, which since has functioned as the hub in Gothenburg's tram network (Trivector Traffic, 2012). Today the Gothenburg tram network is Sweden's largest with approximately 160 kilometers of tracks and just over 100 million trips each year (Göteborgs Spårvägar, 2009). The network is a combination of classic street running tracks and light rail sections. In Figure 3.1 the tram network is displayed and lines are shown with varying thickness based on to which degree they are separated from other traffic.

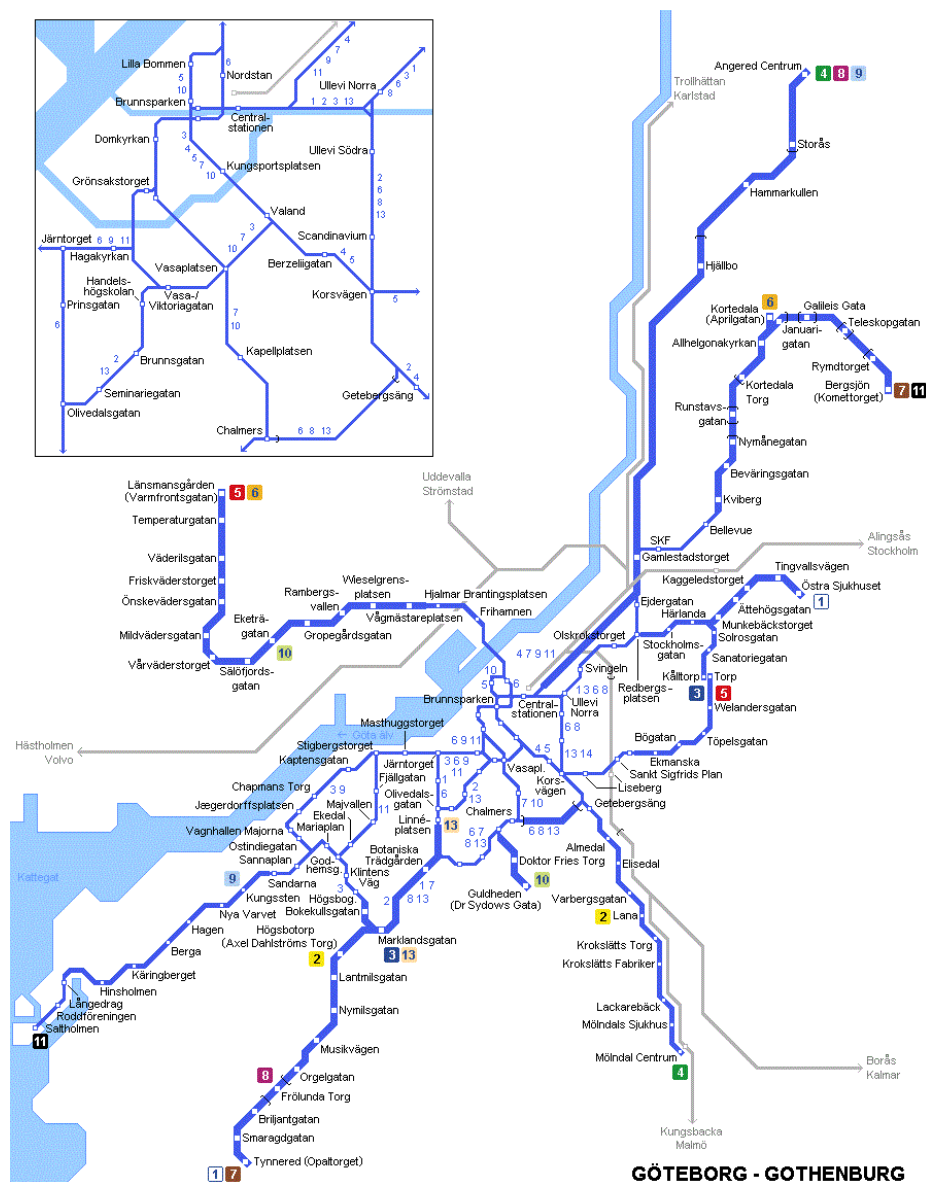


Figure 3.1 Map of the Gothenburg tram network. The thickest blue lines represent trams running on light rail section without level crossings, followed by light rail section with level crossings and lastly street running sections (Lenngren & Schwandl, 2009 (edited)).



*Light rail is no unambiguous concept, but is rather a generic term for all rail traffic that is neither railway nor subway (Trivector Traffic, 2012). In this Master's thesis the concept light rail refer to tramway sections running on embankments separated from other traffic.*

The light rail sections were, as previously mentioned in Chapter 2.1, to a large extent constructed during the 1960's and 1970's (Lenngren & Schwandl, 2009). The light rail sections, with or without level crossings, constitute 100 kilometers or 62.5 percent of the tram network<sup>3</sup>. The longest consistent light rail section is Angeredsbanan with its approximately 12 kilometers of tracks (Eniro, 2012) and stretches between Angered and Centralstationen, although the light rail section ends at Polhemsplatsen. The section has no level crossings and allows the highest average speed among the legs in the network with about 40 km/h, stops included (Eniro & Västtrafik). This can be compared to the average speed of Stockholm's subway with 30-40 km/h (M Larsson). The remaining light rail sections in the network extend primarily to Tynnered, Bergsjön and Länsmansgården, as seen in Figure 3.1.

Street running sections are for the most part located in the central parts of the network. These sections can be divided between the ones where trams share lanes with buses and the ones that also cars run on. The latter sections have lately decreased as separation between public and private transportation is tried to be obtained<sup>3</sup>. Street running sections constitute 60 kilometers or 37.5 percent of the tram network and the average speed is about 10 km/h (Eniro & Västtrafik). The exact distribution between street running sections with or without car traffic is unknown but is estimated by Peter Rydén at *Trafikkontoret* (the Public Transport Authority) to be equally distributed<sup>4</sup>.

Apart from the tram traffic, buses and boats also operate the local public transportation network in Gothenburg. In Figure 3.2 the market share for the three types of transports are shown between 2007 and 2011, described with thousands of trips on the y-axis. In percentage of the total market share this is translated to just over 60 percent for trams, almost 40 percent for buses and less than 1 percent for boats.

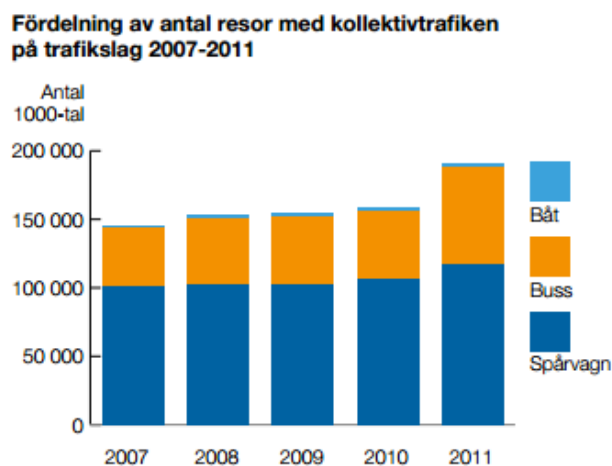


Figure 3.2 Total market share in local public transportation in Gothenburg for trams, buses and boats (Trafikkontoret, 2012).

<sup>3</sup> Peter Rydén (Project leader, Trafikkontoret) e-mail 2012-03-07

<sup>4</sup> Peter Rydén (Project leader, Trafikkontoret) e-mail 2012-03-14

The by far most frequented junction point in the network is Brunnsparken, where 10 out of total 12 tramlines passes through at a frequency of 9-10 minutes during peak hours (Västtrafik, 2012). Brunnsparken has during peak hours a practical capacity limit of around 40 trams per hour and Brunnsparken is today operated far beyond its practical capacity. Future plans are that bus lines will be rerouted from the area in order to free space for tram traffic. The second most overburden junction point is Chalmers, which after the completion of the first Kringen phase was shortened in order to adapt to the newly built Chalmerstunneln<sup>5</sup>.

The vision from K2020 for the future tram network has previously been viewed in Figure 2.4, with its large beltway structure called *Storkringen*. The only planned extensions for the tram network are however the final two phases of Kringen as described in Chapter 2.2. The second phase is planned to be finished in 2015 (Älvstranden utveckling, 2012) although the detailed development plan is currently being appealed against. The third phase Operalänken cannot be constructed prior to the completion of Västlänken, which is planned to around 2028 (Trafikverket, 2011).

### 3.1 Tram lines

Table 3.1 Operating tram lines with respective number of stops, track length, travel time and average speed (Västtrafik & Eniro).

Line	Route	Stops	km	min	km/h
1	Tynnered – Östra Sjukhuset	33	15.6	49	19.1
2	Högsbotorp – Mölndal	27	12.9	39-40	19.4-19.8
3	Marklandsgatan – Kålltorp	30	12.7	45-46	16.6-16.9
4	Angered – Mölndal	21	19.3	41	28.2
5	Länsmansgården – Torp	29	13.8	37-40	20.7-22.4
6	Länsmansgården – Kortedala	46	24.6	73-74	19.9-20.2
7	Tynnered – Bergsjön	35	21.1	54-55	23.0-23.4
8	Frölunda – Angered	25	21.3	47	27.2
9	Kungsten – Angered	21	19.0	42-43	26.5-27.1
10	Eketräsgatan – Guldheden	23	8.8	31-32	16.5-17.0
11	Saltholmen – Bergsjön	38	21.8	57-59	22.2-22.9
13	Sahlgrenska - Brämregården	13	7.9	23	20.6

<sup>5</sup> Kent Lindahl (Head of planning, GS Spårvagn AB) e-mail 2012-03-13

12 tram lines frequent the Gothenburg tram network as seen in Figure 3.1, the veteran line Lisebergslinjen excluded. The operator Göteborgs Spårvägar AB, which is owned by Gothenburg municipality, operates the traffic as a subcontractor to the county council Västra Götalandsregionen (Västtrafik, 2007).

## 3.2 Vehicles, combinations and platforms

The Gothenburg tram network has currently (March 2012) 247 trams available for traffic. The tramcars are denoted by the series M28, M29, M31 and M32 as seen in Figure 3.3. Model M28 and M29 are altogether owned in 118 copies<sup>6</sup> and were manufactured in the 1960's and 1970's. They usually operate coupled in pairs and measures 30 meters. Series M31 was manufactured in the 1980's, is owned in 80 copies and also measures 30 meters. Series M32 is operating the network since 2006 and is currently owned in 49 copies. A second batch of M32 tramcars is in delivery and a total of 65 copies are planned to be in operating the network in the autumn of 2012. The length of the M32 is also around 30 meters<sup>7</sup>.

At peaks hours in the morning and afternoon, 80 percent of the rolling stock is operating the network. The remaining vehicles are in depot for service, maintenance, reparation, removal of graffiti or they are operating the network for educational purposes. The capacity of a 30 meters tram set is 190-195 sitting or standing passengers<sup>5</sup>.

The maximum allowed length of a tram set at station is 30 meters. Prior to the completion of Kringen's first phase, sets of trams longer than 30 meters could operate the Gothenburg tram network. The M28/M29 model could operate triple linked and M31, which at the time lacked the middle low-floor section and was called M21, was operated double linked. These combinations formed sets of approximately 45 meters in length<sup>6</sup>.

With Kringen's first phase, described in Chapter 2.2, problems arose with the project's station lengths. The new junction points, especially Chalmers and Järntorget, were limiting the tram lengths and a decision was made on a transition to shorter tram sets. The transition resulted in a redistribution of the resources and shorter trams sets could now operate on more routes at a higher frequency. These measures resulted in a major increase in travelling in the Gothenburg tram network<sup>8</sup>.



Figure 3.3 Tramcars of series M28, M29, M31 and M32 (Svenska spårvägar, 2008 (edited)).

<sup>6</sup> Kent Lindahl (Head of planning, GS Spårvagn AB) e-mail 2012-03-13

<sup>7</sup> Jörn Engström (Head of public transportation, Trafikkontoret) e-mail 2012-03-03

<sup>8</sup> Kent Lindahl (Head of planning, GS Spårvagn AB) e-mail 2012-03-13

### 3.3 Future expected travelling

As previously mentioned in Chapter 2.4, the K2020 project aims at increasing the market share for public transportation in the Gothenburg region from 24 to 40 percent at latest in 2025. The expected increase of the number of trips in public transportation differentiates within the region and also between regional and local traffic. For Gothenburg's local traffic (trams, buses and boats) the travelling between 2006 and 2025 is expected to increase with a factor 2.06. This means an increase from 138.8 to 285.3 million trips within Gothenburg's local public transportation in 2025 (Västtrafik, 2010). On condition that the tram traffic will remain its 60 percent market share in local public transportation, this generates 171.2 million trips per year or around 470 000 trips per day by tram in Gothenburg.

Årliga resandemål, miljoner delresor/år							
Måltal	Gbg Stadstr.	Gbg Regiontr.	Fyrbodal	Sjuhärad	Skaraborg	Regiontrafik	Västtrafik
2006 utfall	138,8	28,5	11,84	10,77	6,55	5,50	201,9
2010	156,6	32,2	11,53	11,57	7,03	6,76	225,8
2011	161,8	32,9	11,76	12,54	7,16	6,31	232,5
2012	166,7	34,1	12,00	12,76	7,29	5,59	239,4
2013	180,0	36,6	11,79	12,99	7,42	7,94	256,7
<b>Faktor 13/06</b>	<b>1,30</b>	<b>1,28</b>	<b>1,00</b>	<b>1,21</b>	<b>1,13</b>	<b>1,44</b>	<b>1,27</b>
2014	189,0	38,1	12,07	13,23	7,55	8,30	268,3
2015	194,7	39,8	12,36	13,47	7,69	8,67	276,7
2016	200,5	41,5	12,66	13,71	7,83	9,06	285,3
2017	206,5	43,4	12,96	13,96	7,97	9,47	294,3
2018	212,7	45,3	13,27	14,21	8,11	9,89	303,5
2019	219,1	47,3	13,59	14,46	8,26	10,39	313,1
2020	227,9	49,4	13,92	14,72	8,41	11,01	325,4
2021	237,0	51,7	14,25	14,99	8,56	11,67	338,2
2022	246,5	54,1	14,59	15,26	8,71	12,49	351,6
2023	258,8	56,5	14,94	15,53	8,87	13,36	368,0
2024	271,7	59,2	15,30	15,81	9,03	14,30	385,3
2025	285,3	61,9	15,67	16,10	9,19	16,44	404,6
<b>Faktor 25/06</b>	<b>2,06</b>	<b>2,17</b>	<b>1,32</b>	<b>1,49</b>	<b>1,40</b>	<b>2,99</b>	<b>2,00</b>

Figure 3.3 Yearly goals by Västtrafik (2010) in millions of trips per year.

## 4 Tunneling in clay

Constructing tunnels in cities like Gothenburg, where a large part of the buildings in the city center are founded on clay, is challenging and often very expensive. This chapter presents examples of three different city tunneling projects, gives an overview of the geotechnical conditions in Gothenburg and describes the most common method of tunneling in clay.

### 4.1 Examples of city tunnels situated in clay

#### 4.1.1 The Amsterdam Metro

The Amsterdam metro is a combination of a metro and a light rail system. Apart from a tramway tunnel on route 26, only 3.5 kilometers of the system run underground (Lenngren & Schwandl, 2009). The city is founded on sediments of sands, silts, clays and peat with depths down to 1000 m below ground level (Herbschleb & de Wit).

The construction of the metro system started with the so-called east line in the second half of the 1960's. The line was opened first in 1977 after years of protesting from the people of Amsterdam and a major misestimating of costs. Due to the many problems of the construction of the east line, the continuation of the metro project was abandoned and it was decided that no future metro line would run underground (Spangenberg).

In spite of the problems with the east line a new underground line, the north-south line, was started to be built in 2002. The project was set to finish in 2012, but after major setbacks the line now is planned to be operating in 2017 (Spangenberg). The setbacks were mainly due to problems with the soft clay, which among other things caused historical houses to subside and Amsterdam's budget deficit to skyrocket (Nrc.nl, 2009). Excavation was mainly done along the existing streets in the city, since excavation below the buildings would demand major demolitions or massive and very expensive reinforcements of the buildings. The depths of the excavation pits for the stations exceeded 30 meters, which in combination with difficult soil conditions created huge problems for the adjacent historical buildings along the route (Herbschleb & de Wit). The cost of the north-south line was initially estimated to 1.4 billion euros, but is now estimated to around 3 billion euros (Nrc.nl, 2009).

#### 4.1.2 Haag tramway tunnel

The Haag tramway tunnel is a 1250 meters long tunnel situated in central Haag in the Netherlands. The official name of the tunnel is *Souterrain*, meaning "under ground" and is a three-storey underground structure with a tramway tunnel on the bottom floor and an overlaying two-storey underground car park (Leijten, 2009).

Construction of the tunnel started in 1996, but much like with the Amsterdam metro problems quickly arose due to the problematic geotechnical conditions. A method of first building the tunnel walls and roof was applied to reduce the inconvenience at street level. The excavation was then initiated from under the tunnel's roof. In spite of this precautious method, a rupture caused an unstoppable leak which lead to subsidence of superjacent buildings. To prevent further subsidence the tunnel had to

be flooded completely and was consequently given nicknames such as *the Tramtanic* (Dutch OMEGA team).

The incident was due to the decision of not using the conventional method of a building pit with an underwater concrete floor with tension piles, but instead to use an experimental deep arch-grouting technique (Van Baars, 2011). In comparison to the Amsterdam case, the soil consisted mainly of homogenous sand and a layer of peat. There were however several thin layers of clay just above the grout layer. These conditions were not known and caused the pore pressure to build up between the grout and the clay layer and eventually the grout layer ruptured (ITA, 2003).

The opening of the tunnel was delayed from 1999 to 2004 and the costs of construction increased from the budgeted 139 to 234 million euros (Van Baars, 2011). The western tunnel entrance and the interior of the tunnel are viewed below in Figure 4.1.



Figure 4.1 West tunnel entrance from street running tracks (Archined, 2004) and interior of station at Haag tramway tunnel (Flickr.com, 2009).

### 4.1.3 Götatunneln

Götatunneln is a tunnel in Gothenburg that is a combination of two end parts of concrete tunnel situated in clay and an intermediate rock tunnel. The tunnel was constructed between 2000 and 2006 and was the year after completion in 2007 frequented by 42 600 vehicles per day (Göteborgs Stad, 2008). The initial estimated cost was just over 1.8 billion SEK but the final sum amounted to 3.4 billion SEK (Papaioannou, 2011). The almost doubled initial sum was not a result of major changes of the construction, but rather a consequence of an increase in price levels between the first budget in 1998 and the final sum in 2006 (Sahlberg, 2007).

The length of the tunnel is 1.6 kilometers whereof 1 kilometer in rock and 0.6 kilometer in soil. The concrete tunnels were to a large extent constructed in difficult conditions in soft clay with a high risk of causing settlements. Excavations in these parts were as deep as 20 meters and the structural support was driven to a depth of 30 meters below the surface (Bergsäker, 2006). The method of excavating was cut-and-cover, described further in Chapter 4.3, with steel sheet pile walls and diaphragm walls as supporting structures. Götatunneln is most likely the most challenging geotechnical project to this date, with its deep excavation pits in a complex urban area (SGI, 2004).



## 4.2 Geotechnical prerequisites in Gothenburg city

The geology in Gothenburg city is characterized by outcrops of rock surrounded by areas of clay, often down to massive depths (Banverket et al., 2002). The area along the river Göta älv, Södra älvstranden, consists of particularly deep layers of clay down to 100 meters (Stadsbyggnadskontoret, 2010). The clay rests on friction soil on top of the bedrock that for the most part is crystalline with gneiss as rock type. Elements of magmatic rock types such as diabase can also be found in the gneiss (Banverket et al., 2006c). The approximate depths to the bedrock for the central parts of Gothenburg are shown below in Figure 4.2.

The difference in ground level heights between the area within the old moat and the mountain areas in the south is about 50 meters (Banverket et al., 2006d). In the low-lying areas north in the map, the clay is normally covered by 1 to 3 meters of fill, locally also with a dry crust. In some central areas the fill extends down to 7 meters as a result of a previously performed refilling of former canals (Banverket et al., 2006c).

The crystalline bedrock in Gothenburg is of relatively good quality for rock tunneling. Measures must however be taken to minimize the impact on the groundwater levels when tunneling, which is an inevitable factor to consider when tunneling in rock (Banverket et al., 2006d). The clay in the area is soft to very soft and normally consolidated or slightly over consolidated. The clay is hence very likely of causing settlements, which may cause large movements and stability issues when excavating (Banverket et al., 2006d). Appropriate stability measurements are thus a necessity when excavating in the clay.

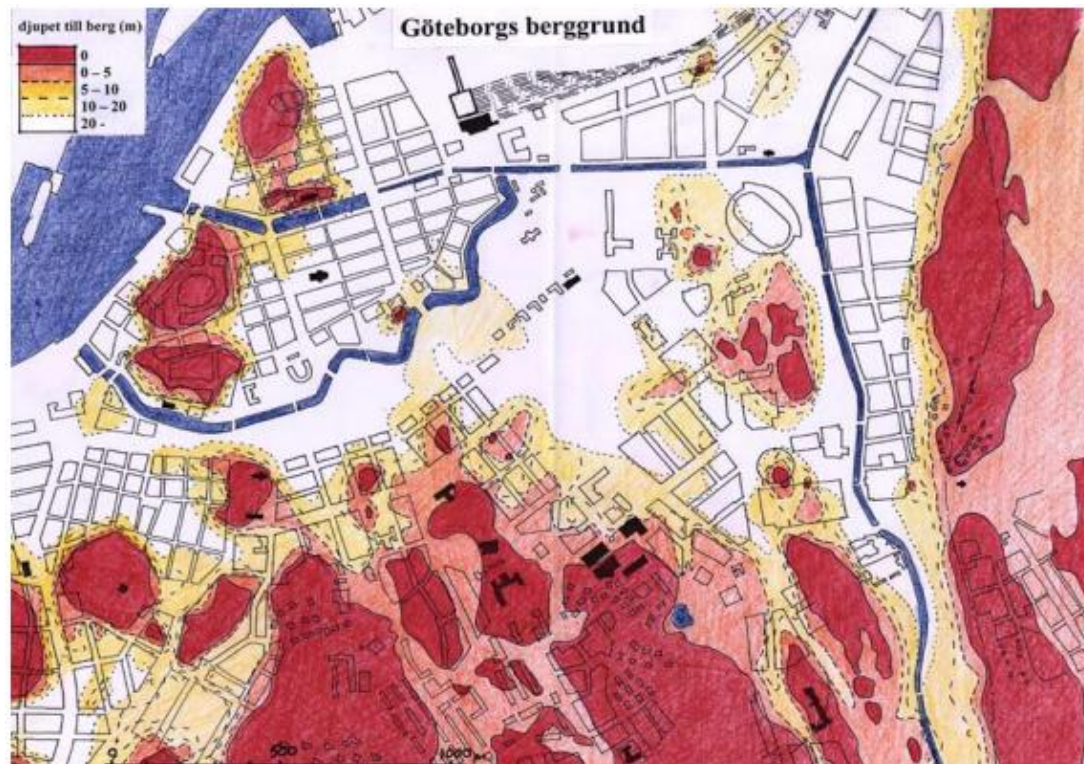


Figure 4.2 *Bedrock map of central Gothenburg. The red areas represent outcrops of rock and the white area represents soil depths deeper than 20 m. Remaining colors cover the depths in between (Banverket et al., 2001)*

### 4.3 The cut-and-cover method

The cut-and-cover method is commonly used when constructing tunnels in urban areas with weak ground conditions, such as in clay (Mouratidis, 2008). The procedure of the method varies depending on the properties along the corridor. In the case where a wide corridor of land is available, e.g. in rural environments, the conventional method can be used which implements a 2:1 slope along the route (DRIC, 2007).

In urban areas however, narrow corridors is often required due to adjacency of existing structures. The cut-and-cover method is then implemented through either the top-down or the bottoms-up approach. In the top-down approach concrete walls are cast, followed by the roof and tunnel floor. In the bottoms-up approach the line of action for tunnel floor and roof is reversed (Mouratidis, 2008).

Construction of the tunnel can be done in stages and thus maintain a large part of the existing traffic along the corridor (DRIC, 2007). Implementation of the cut-and-cover method in urban environments demands however, in comparison to rock tunneling, traffic rerouting and disruption of existing public transportation routes. The advantage of this method is that a stable tunnel construction can be created in very unstable soil conditions. One disadvantage, in comparison to rock tunneling, is that an open excavation pit is needed which requires removal of overlying matter. Another disadvantage is that concrete tunnels generally are five to ten times as expensive as a rock tunnel (Banverket et al., 2006b). The casting of a cut-and-cover tunnel with the conventional method for the Krakow fast tram project is shown in Figure 4.3.



Figure 4.3 Construction of a cut-and-cover tunnel in Krakow, Poland (Skyscrapercity Forums, 2007).



## 5 Results

This chapter is the thesis' most extensive and contains the results based on the thesis' purpose. The chapter is divided into seven subchapters that present a design of a tramway tunnel construction in Gothenburg, describe the prerequisites for the design and discuss the potential effects. The creator of the initial idea for the tramway tunnel is Patrik Sterky, railway engineer at the consultancy company Ramböll and also the supervisor during the writing of this master's thesis. Below are Patrik's own words on the origin of the idea;

*“The Gothenburg tram network is today characterized by large differences in standards. The outer parts of the network mainly consist of embankments separated from other traffic, while the central network is street running with low average speeds, short platforms and small radiuses. Almost every tramline passes through the highly loaded crossing in Brunnsparken, which already today leads to a significant deficiency when it comes to disruptions and capacity. The central parts of the network is hence the area that primarily is in need of a new infrastructure in order to increase the capacity and the average speeds, as well as enabling longer and more capacity strong trams to meet the needs of tomorrow.*

*The idea of a tramway tunnel in Nya Allén has been on my mind for some time now. The area, combined with a rock tunnel in Linnéstaden, enables a central tramway corridor which connects the existing light rail sections at Polhemsplatsen and Linnéplatsen, but not necessarily to the major costs usually associated with tunnel solutions through the central area of Gothenburg. A master's thesis like this provides an excellent opportunity of presenting the idea and investigates what the benefits could be for the future public transportation in Gothenburg.”*

Patrik Sterky, May 3<sup>rd</sup> 2012

The previous chapters have among other things told about the history and the present state of the Gothenburg tram network. The city is growing and in 2008 the total number of inhabitants in Gothenburg's municipality reached 500 000 (Carnhede, 2008). Some projects are planned in order to increase the capacity of the central tram network. These are mainly the mentioned remaining phases of Kringen: *Spårväg Skeppsbron* and *Operalänken*. The trams operating on Kringen's second phase, between Järntorget and Lilla torget, will still however pass through Brunnsparken and Operalänken have not yet been investigated.

A simulation performed by Ramböll (2011) investigated the future traffic situation in the area around Brunnsparken and Drottningtorget. Several different scenarios were investigated where parts of the bus traffic were removed from the area and certain tram stops were moved in order to decrease the congestion. The scenario that managed the traffic situation in the area best by the year 2020 still showed that the congestion and delays would increase compared to today's situation. As a result of this, the travel time through the area would increase with 20-30 percent.

An investigation by Trafikkontoret, on the possibility of extending the existing tram platforms, showed that an extension would not result in a sufficient increase of capacity in the long run. The investigation also showed that it would be very hard to extend many of the centrally located platforms, where the majority of the tram lines pass through<sup>9</sup>. In conclusion, the possibilities of either extending the platforms or increasing the frequency of trams through central Gothenburg are poor.

This thesis have so far showed a tram network in Gothenburg that works well in the outer parts of the city with mostly reserved tracks with high average speeds as a result, but poor centrally with congestion and low average speeds. It has also been showed that the possibilities for a subway construction centrally are very limited as the densely built-up center to a large part is founded on deep layers of clay. With expectations of a major increase of public transportation according to K2020, the need of new solutions for the central part of Gothenburg's tram network is apparent.

## 5.1 Introducing Allélänken

The only centrally located undeveloped area in Gothenburg of significant size is the "green belt" south of the old moat. The area consists of the parks *Trädgårdsföreningen* and *Kungsparken* that is intersected by the roads *Nya Allén* and *Parkgatan*, previously viewed in Figure I. Since the area along *Nya Allén* has not been developed, it enables a construction of a tramway corridor centrally that could relocate trams from the heavily loaded *Brunnsparken* and increase the capacity of the network as well as decreasing the travel time.

Allélänken is a proposal that connects the outer light rail sections from Angered and Tynnered, via a centrally located tramway tunnel with four stations. The tunnel connects to existing tracks at *Polhemsplatsen* and *Linnéplatsen*, which together with the previously built light rail sections create a fully reserved track between Angered and Tynnered. Since the problems with an extension of the existing platforms mainly concerned the central area of the network, extensions of the outer station platforms could enable traffic with longer trams with a high capacity.

In order to enable fast transports with a high capacity within the city, grade separation from other traffic is required. The proposal enables this with a 2.7 kilometers long concrete tunnel between *Polhemsplatsen* and *Hagabion* combined with a 0.8 kilometers long rock tunnel the remaining distance to *Linnéplatsen*. The stations included in the design are *Centralstationen*, *Avenyn*, *Haga* and *Järntorget*. The corridor of the approximately 3.5 kilometer long tunnel is shown in Figure 5.1, together with the station locations.

The station locations of Allélänken correspond well with the ideas in the public transportation program by GR et al. (2009) where *Nya Allén*, *Avenyn* and *Hagakyrkan* were identified as important areas for the future of public transportation in Gothenburg. This implies, together with the decided route of *Västlänken*, that new areas in the city besides *Brunnsparken* and *Drottningtorget* will become increasingly more important for the public transportation.

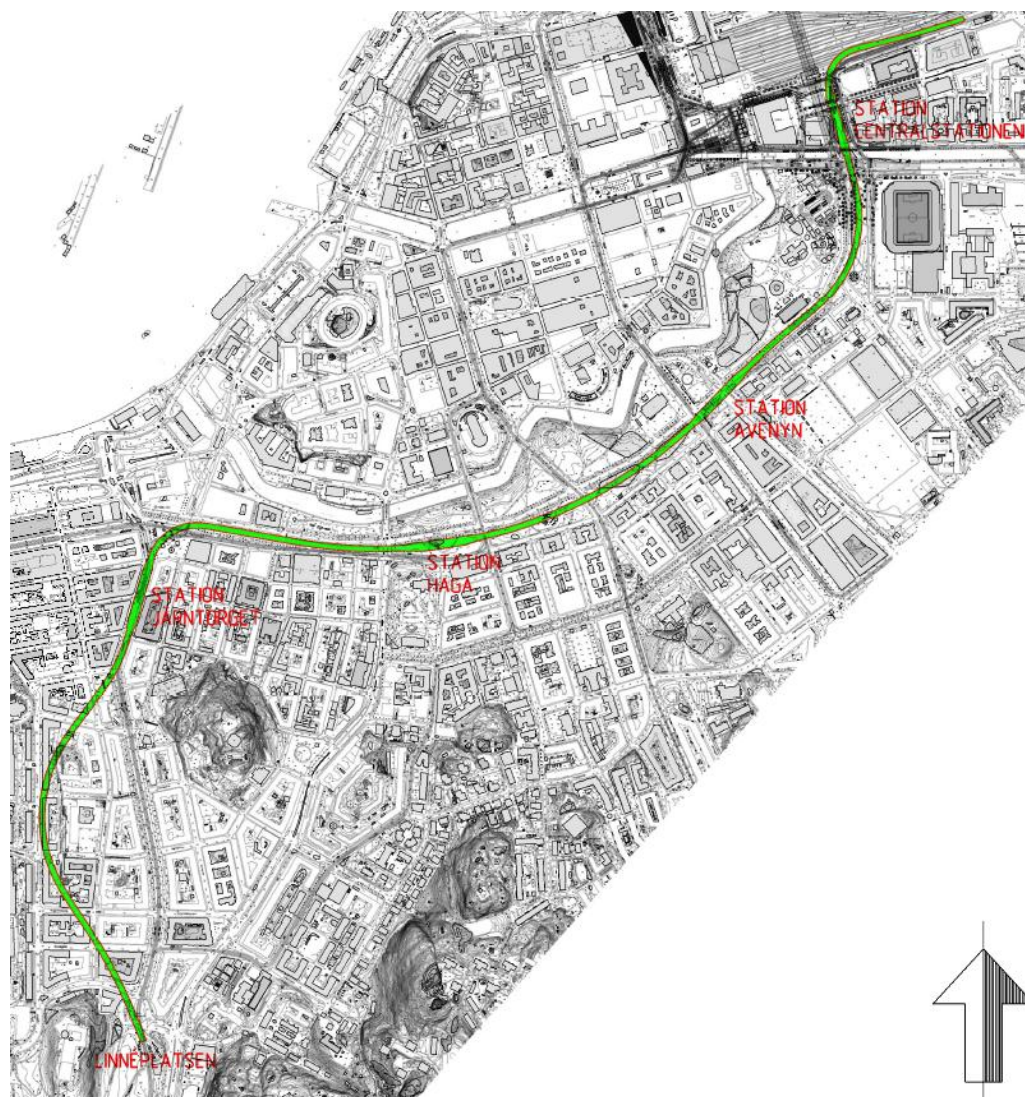
To enable a high capacity in the tunnel the stations are designed with a platform length of 110 meters. A city similar in size to Gothenburg is Oslo in Norway where conversion from tram network into subway is an ongoing project (Schwandl, 2011).

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<sup>9</sup> Jörn Engström (Head of public transportation, Trafikkontoret) e-mail 2012-03-03

The platforms in Oslo's subway are being adapted to 110 meters to increase the capacity of the network and the 54 meters long metro trains are often operating double linked as 108 meters sets (Oslo Kommune, 2003). The station length of 110 meters has thus been considered reasonable also for Allélinken, although initially it is more likely to double link the existing vehicles to tram sets of 60 meters.

Allélinken intersects with the corridor of Västlinken near Hagakyrkan. Västlinken is located at a depth of approximately 24 meters (Banverket et al., 2006f), which thus could enable an intersecting superjacent shallow tunnel. Allélinken can however be realized only after the completion of Västlinken, since the clay in the area requires excavations. The choice of diverging into the bedrock at Hagabion is due to the fact that rock tunnels are less expensive, as mentioned in Chapter 4.3, and that interference along Linnégatan should be avoided. The geometry of the rock tunnel, between Hagabion and Linnéplatsen, is however uncertain due to lack of geotechnical data. The connection to existing station at Linnéplatsen has not been investigated further due to these uncertainties.



*Figure 5.1 The corridor and stations of Allélinken. A larger version of the map is found in Appendix I. Detailed maps in scale 1:1000 is found in Appendix VI.*

One advantage of the proposed route is that it does not require demolitions of existing structures, which most probably would be necessary if a network similar to the previous investigations presented in Chapter 2.1 were built. By this, the tunnel can be located shallowly and will thus not require deep excavation pits and challenging retaining structures as in the case of Götatunneln and Västlänken. The costs of the tunnel can thus be relatively limited compared to similar urban tunneling projects. Another advantage of the route along Nya Allén is that it enables good track geometry with large radiuses and also makes it possible to some extent maintain the traffic at the mentioned roads during construction time.

This introductory chapter has briefly introduced the prerequisites and the design of Allélänken. The following chapters will further elaborate and investigate prerequisites, the design and potential effects of Allélänken. The purpose and intended effects of the proposal can be summed up in these five goals:

- An unburdening of Brunnsparken achieved by redistribution of tram traffic
- Significantly reduced travel time through central Gothenburg
- Achieve a high capacity by designing long station platforms
- Decreased the vulnerability of the central tram network
- Enable strategic future extension possibilities

## 5.2 Area description

The chosen corridor for Allélänken is located in an urban environment of varying character depending on where along the route you are. This naturally leads to different prerequisites in terms of planning and building of an urban infrastructural project like Allélänken. Three areas of different character have been defined and are further described in this chapter. The areas are Polhemsplatsen, Nya Allén and Linnégatan. The location of the areas along the route of Allélänken is viewed in Figure 5.2.

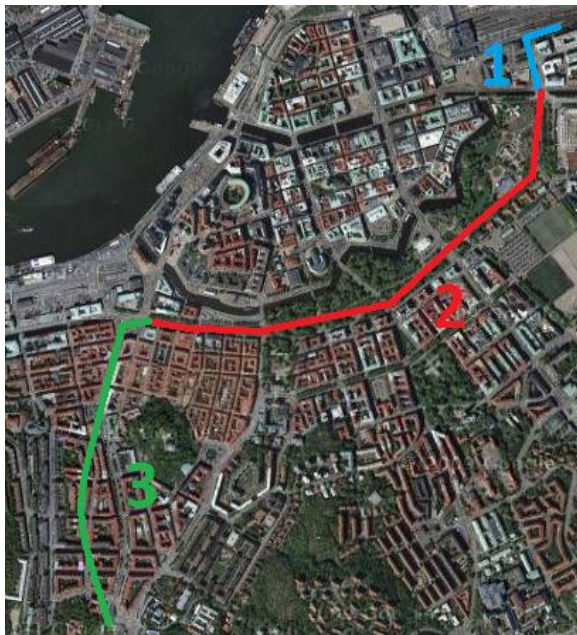


Figure 5.2 The three areas described in the chapter: 1-Polhemsplatsen, 2-Nya Allén, 3-Linnégatan (Google Maps, 2012 (edited)).



### 5.2.1 Polhemsplatsen

Polhemsplatsen can be described as a roundabout for cars and buses intercepted by tramway tracks connecting to Angeredsbanan, see Figure 5.3. The area is confined by *Fattighusån* (1) in the south, *Clarion Hotel Post* (2) in the west, rail tracks of the central station (3) in the north and among other buildings the *GP-huset* (4) in the east.

Major changes are planned in this area as a result of the planned flyover *Bangårdsviadukten*. A detailed development plan for *Bangårdsviadukten* has not yet been presented, but the preliminary design of it by Ramböll is viewed along with Allélänken's Station Centralstationen in Appendix VI. The flyover is planned as a four lane road, two lanes in each direction, with bicycle path and a sidewalk (Ramböll, 2012).

As previously viewed in Figure 4.2, the area is founded on deep layers (>20 meters) of clay. Tunnel construction in the area requires thus the cut-and-cover technique with open excavation pit. Since the location of Allélänken, as previously seen in Figure 5.1, is between the planned *Bangårdsviadukten* and the eastern buildings, no demolitions or reinforcements of existing structures should be required in this area. Rerouting of traffic, trams included, is however required during the construction time.

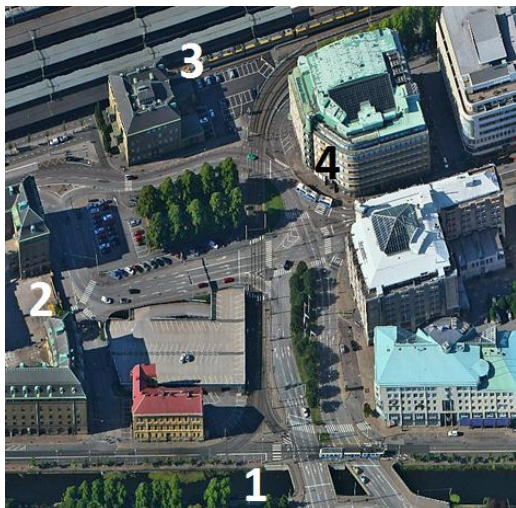


Figure 5.3 Air photograph of Polhemsplatsen (Eniro, 2012 (edited)).

### 5.2.2 Nya Allén

Gothenburg was a fortified city, surrounded by its moat and city walls, up until 1806 when it was decided that the fortification would be abolished. In the demolition contract it was stated that the city of Gothenburg would plant an avenue outside the moat. The avenue was named *Nya Allén* (the new avenue) and was planted in 1823, not to be mistaken for *Gamla Allén* (the old avenue) along Heden's west side. *Nya Allén* was intended for both pedestrians and transports and was planted with four tree lines. In addition to this, the parks *Trädgårdsföreningen* and *Kungsparken* were planted between *Nya Allén* and the moat during the years 1839-1860 (Banverket et al., 2006g).

Today the area along *Nya Allén* is primarily characterized by park environment, mainly constituted by the parks *Trädgårdsföreningen* and *Kungsparken*. *Kungsparken*

surrounds most of the avenue that creates a park environment between the westbound avenue Nya Allén and the eastbound road *Parkgatan*, each with three car lanes. The westbound road has outer bicycle paths in both directions and the park holds several small walking paths, a miniature golf course, among other things. In the west part of the marked stretch close to Järntorget, the roads *Norra Allégatan* and *Södra Allégatan* confine the avenue. A typical view from the area is shown in Figure 5.4, where the four tree lines of Nya Allén can be seen to the left and some single larger trees that are located in the park area in between the roads.

The approximate total length of the avenue, marked with red in Figure 5.2, is 1800 meters and stretches between Fattighusån in the east and Järntorget in the west. In the background report concerning parks and natural environments for the Västlänken project (2006e), the experience value of Nya Allén was considered to be high. In the report, the large number of trees is considered to be of great importance for the cityscape as well as for the air environment.

As mentioned previously in Chapter 5, Nya Allén is a unique area in Gothenburg since its significant size in combination with the central location creates opportunities for a tunnel construction like Allélänken. The inevitable fact is however that the area is founded on clay that extends deeply in the area near Fattighusån, as previously seen in Figure 4.2. Tunnel construction in Nya Allén requires hence the cut-n-cover technique with open excavation pits and removal of overlying matter. Regardless of the design of Allélänken, intrusion in the park environment is inevitable. To which degree this has to be done is elaborated further in Chapter 6.3.



Figure 5.4 A typical view along the avenue Nya Allén.

### 5.2.3 Linnégatan

Linnégatan is an 1100 meters long street between Järntorget and Linnéplatsen, located in the district Linnéstaden. The street is lined with houses, mostly of which are built in the beginning of the 20<sup>th</sup> century (Förvaltnings AB Göteborgslokaler). The street holds street running tram tracks and is today frequented by lines 1, 6 and also a shorter part by line 2. Buses, cars, bicyclists and pedestrians make up the remaining traffic along the street.



The area where Linnégatan today is located was previously the location of the stream *Djupedalsbäcken* that north of the street fell into Göta älv. The area was in 1879 filled and the stream was led north by an underground culvert (Förvaltnings AB Göteborgslokaler). The culvert still exists today and needs to be considered when excavating for a tunnel.

The area of interest for Allélänken is shown in Figure 5.5. As can be seen previously in Figure 4.2, the north part of the area in the picture below consists of clay and the south by outcrops of bedrock. Allélänken is planned as a concrete tunnel from Polhemsplatsen to the parking lot shown in Figure 5.5. At this particular place, the depth to the bedrock is about 5-10 meters, which enables a transition from concrete tunnel to rock tunnel the remaining stretch up until Linnéplatsen.

The distance between the houses along Linnégatan in this area is about 30 meters (Stadsbyggnadskontoret, 2012). This prerequisite places high demands on the line of action during the tunnel construction and careful measurements of vibrations and settlements have to be performed in the adjacent buildings. The area around Järntorget will first and foremost require a large-scale rerouting of tram, bus and car traffic.



*Figure 5.5 The part of Linnégatan intended for Allélänken. The geometry of the tunnel in this picture is merely a sketch and is thus not accurate (Eniro, 2012 (edited)).*

### **5.3 Station locations**

The choice of placement for Allélänken's stations is of great importance, as the accessibility to the stations should be maximized in order to provide a good public welfare. An analysis by the author and supervisor Patrik Sterky was made in order to settle appropriate station locations along the route based on the current as well as possible future city structure in Gothenburg. As previously mentioned, the proposed

stations are Centralstationen, Avenyn, Haga and Järntorget. The surrounding areas of each station and their specific conditions are described further in this chapter.

For each station it has been applied a method of illustrating the area it influences. The method is based on the approach in the background report by Banverket et al. (2006h) concerning social consequences for the Västlänken project. For each station, spheres of 400 and 800 meters are applied which represent the distance an average person can walk in 5 and 10 minutes. The 5-minute distance is often used as a measure of the proximity to grocery stores, whilst the 10-minute distance represents the distance of a person's willingness to walk without heavy luggage.

The spheres purposes are mainly to identify which area of the city that is affected and gets access to each of the stations. In the case of Allélänken, the 400 meters/5-minute sphere is perhaps of greatest importance since the willingness to move most probably is lower for travellers by tram than for trains, as in the case of Västlänken. For each station, the track design and the corridor are also presented. Further analysis of the influenced areas is dealt with in Chapter 6.2.

### 5.3.1 Centralstationen

The area around Gothenburg central station is an important junction point for train as well as tram traffic. In 2006 the number of trips with train was 40 000 in the Gothenburg area and a major increase of this number is expected in the future, mainly on Norge/Vänerbanan and Västra Stambanan. As a result of Västlänken, passengers travelling by train have access to the new stations at Haga and Korsvägen. In spite of this, the number of trips with train made at Gothenburg central station is expected to increase to 51 200 after the completion of Västlänken (Banverket et al., 2006a). The adjacency to Drottningtorget, with its high frequency of trams and buses passing through, makes the location of Allélänken's Station Centralstationen highly justifiable. The proposed location of the station and its area of influence are shown in Figure 5.6.



Figure 5.6 Location of Station Centralstationen and the area it influences (Google Maps, 2012 (edited)).



The station is located at Polhemsplatsen, in between the future flyover Bangårdsviadukten and the adjacent eastern buildings. The station is planned to be located deeper, approximately 10-12 meters below ground level, than the other stations of Allélänken. The reason for this is mainly the need of passing under Fattighusån. The depth of 10-12 meters also enables the possibility of implementing a mezzanine. A mezzanine is an intermediate floor between the platforms and the tunnel roof where for instance stores like *Pressbyrån* and cafés can be located. The intermediate floor also enables an underground connection for pedestrians to the train station and Drottningtorget. The situation for pedestrians at Polhemsplatsen today is poor with heavy traffic in just one plane. Plane separated connections to these important junction points are thus a way of creating a safe accessibility to Station Centralstationen. An example of a mezzanine in Krakow Rapid Tram system is shown in Figure 5.7.

As the right part of Figure 5.6 shows, the 5-minute sphere contains the entire Gothenburg central station area including the bus station *Nils Ericssonterminalen*, parts of Brunnsparken and the densely populated area along *Odinsgatan* among other things. The station location enables thus a good accessibility to a number of important destinations.



Figure 5.7 A mezzanine at a tram station in Krakow, Poland (Prodan, 2009).

### 5.3.2 Avenyn

The north part of the street Kungsporsavenyen, *Avenyn* in everyday speech, is a popular strolling path that offers a wide range of restaurants and pubs among other things. The station is located at the beginning of Avenyn in the area of *Charles Felix Lindbergs plats*. The prerequisites and the possibility of using this particular area as a public transportation junction point was in 2009 presented in the public transportation program *Kollektivtrafikprogram för Göteborgsregionen* (GR et al., 2009) in the K2020 project. A sketch from this report of a suggestion to this future junction point is shown in Figure 5.8. One of the proposed ideas was in the report that the car traffic along *Nya Allén* and *Parkgatan* would be located underground in two tunnels á 130 meters and that the area above would be used for public transports, bicyclists and pedestrians.



Idéskiss till knutpunkt. Avenyn sedd från Stora Teatern med biltrafik i ett undre plan.

Figure 5.8 Suggestion on a plane separated junction point at Charles Felix Lindbergs plats from the K2020 project (GR et al., 2009).

The background report states that the place itself is not an attractive destination today, but the adjacency to Avenyn’s selection of restaurants and stores together with the park Trädgårdsföreningen and the theatre Stora Teatern makes it an appropriate junction point. In the case of Allélinken, this station together with Station Centralstationen, will to a high extent meet the needs of travellers with Brunnsparken as their destination. As previously mentioned, the area was in the K2020 project identified as an important future junction point in the public transportation network in Gothenburg. The area around Station Avenyn, shown in Figure 5.9, can thus develop into an attractive junction point in the future as a result of an increased flow of traffic from infrastructural projects like Allélinken.

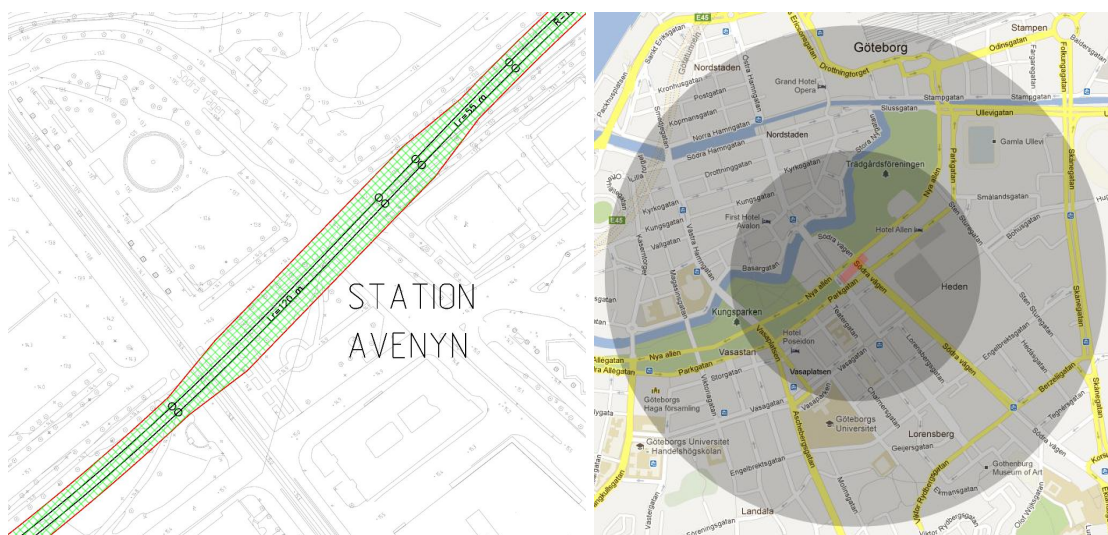


Figure 5.9 Location of Station Avenyn and the area it influences (Google Maps, 2012 (edited)).

### 5.3.3 Haga

Station Haga is located north of the church Hagakyrkan and in connection to the future Västlänken station. The area consists of large centrally located residential areas, many workplaces and the university departments *Handelshögskolan*, *Samvetet* and *Pedagogen* among other things. These university departments will at the completion of Västlänken include over 10 000 students and about 1000 employees, based on the figures of today (Banverket et al., 2006h). The area along the street *Haga nygata* is a popular tourist destination and the majority of the area within the old moat is located within the 10-minute sphere, as seen in Figure 5.10. In the previously mentioned background report by Banverket et al. (2006h) concerning social consequences for the Västlänken project, the number of travellers departing or arriving at Västlänken's Haga station is estimated to be 30 000 per day.

Västlänken's Haga station will, according to Banverket et al. (2006f), be located relatively deep under the church in order to get a sufficient bedrock cover. The estimated depths for the station are 34 meters below Vasagatan and 24 meters below Nya Allén. A construction of Allélänken is as previously mentioned possible only after the completion of Västlänken and Station Haga is planned as the remaining stations except for Station Centralstationen, i.e. relatively shallowly which gives a depth of approximately 6-8 meters to station (measurements of tunnel sections are further elaborated in Chapter 5.4.3). The route of Allélänken results in a passage over Västlänken and a reinforcement of Västlänken's roof at this crossing may thus be necessary. This should be done in the same way as for Götatunneln as described previously in chapter 2.3. Preparations for connections between the two stations should also be considered.

The current tram station *Hagakyrkan* is frequented by 5 tram lines and several bus lines and is today a relatively frequented station. The mentioned background report states that travellers that combine their journey by train with transports within the local public transportation system most probably will use the Västlänken station. The area will to a higher extent than today become vibrant according to the report and a station location here for Allélänken is for the above-mentioned reasons highly appropriate.

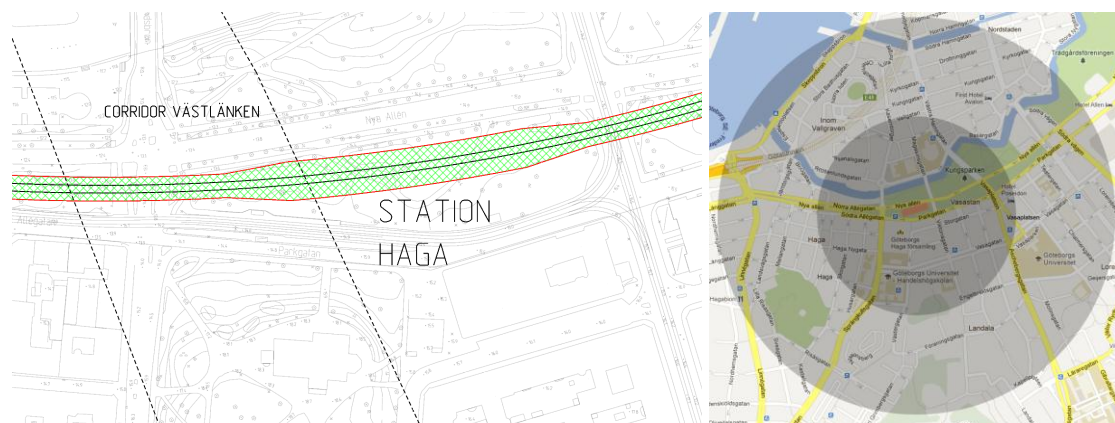


Figure 5.10 Location of Station Haga and the area it influences (Google Maps, 2012 (edited)).



### 5.3.4 Järntorget

Järntorget is today one of the largest junction points in the public transportation network in Gothenburg. The tramway stretches west towards Majorna, south along Linnégatan and east towards the inner city. After the completion of Kringen's second phase the tramway will also stretch north at Järntorget towards Lilla torget. The area around Järntorget offers a wide range of cultural modes and the area is also one of the densest when it comes to restaurants and pubs. This makes Järntorget a popular destination and an important junction point in the public transportation network.

The proposed location for Allelänken's Station Järntorget is located south of the current tram and bus platforms, viewed in Figure 5.11. The demands concerning accessibility on station platforms are high since the aim is to have a minimal gap between the vehicle and the platform. For the Spårvagn City project and the subway in Stockholm the minimum radius in curves is set to 700 meters at stations<sup>10</sup>, which also is the limit used in the design of Allélänken. This fact prevents a station location further north in the curve at Järntorget, which in the design has a radius of 100 meters. A station location east of the curve has not been considered since the adjacency to Station Haga in that case would not be strategic.

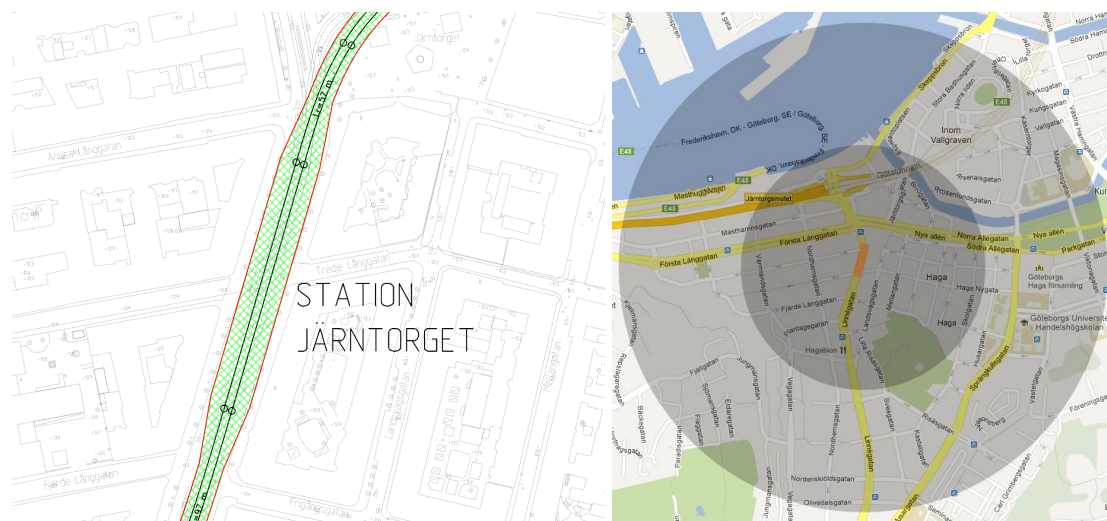


Figure 5.11 Location of Station Järntorget and the area it influences (Google Maps, 2012 (edited)).

The location for Station Järntorget was in two of the investigated alternatives in the pre-study for Västlänken considered for a possible train station. A sketch of this is shown in Figure 5.12. The tunnel would connect from either Hisingen or from the inner city and continue as rock tunnel north of Hagabion south towards the hospital Sahlgrenska (Banverket et al., 2002). Although the two alternatives were discarded after the pre-study, the report shows the advisability of the location as a train or tram station.

<sup>10</sup> Cedric Hanneberg (Railway engineer, Ramböll) e-mail 2012-03-21



Figure 5.12 A suggested station at Järntorget from the Västlänken pre-study (Banverket et al., 2002).

## 5.4 Construction

The focus in Chapter 5 is mainly on the overall design of Allélänken and its surroundings rather than on the specific tunnel design. This chapter presents however brief recommendations on appropriate methods of construction based on the prevailing circumstances. Tunnel sections at station and in between are also presented as well as the expected impacts during construction.

### 5.4.1 Concrete tunnel

The background report by Banverket et al. (2006c) concerning the possible construction methods of Västlänken evaluates two methods of constructing concrete tunnels. These methods are the cut-and-cover method that previously has been described in Chapter 4.3 and also the method of tunneling with a TBM, short for Tunnel Boring Machine. Since the geotechnical prerequisites are equivalent for both Västlänken and Allélänken, these two methods are the most appropriate to evaluate.

The TBM method is usually associated with rock tunneling but can also be used for tunneling in friction materials and clay. A rotating steel cylinder is in this method pushed through the earth and prefabricated concrete segments are subsequently mounted along the line. Two separate circular concrete tunnels are in this way created and the method requires excavations down to greater depths compared to the cut-and-cover method. A simplified method of TBM is box jacking where a rectangular front with hydraulic jacks constructs the concrete tunnel (Banverket et al., 2006c).

The proposed route of Allélänken brings with it certain demands. The corridor width of the route should be kept to a minimum in order to minimize the environmental impact along Nya Allén for instance. The width of the corridor also plays a major role in some critical parts along the route, mainly at the relatively narrow section along Linnégatan and in the area around Polhemsplatsen where adjacent buildings limit the free space. Excavation depths should also be kept to a minimum as this very much is linked with the requirements of retaining structures and costs. The recommendation is to apply the cut-and-cover method for the approximately 2.7 kilometers concrete tunnel construction.

## 5.4.2 Rock tunnel

Rock tunnels are mainly constructed either by the conventional drill and blast method or with a TBM. The line of action for the drill and blast method can briefly be described as drilling horizontal holes in the rock, injecting explosives in the holes and blasting the rock. The method is well tested in the Gothenburg area and can to a high degree be adapted to the prevailing circumstances (Banverket et al., 2006c).

The method of tunneling with a TBM in rock is similar to the method described above for soil conditions. TBMs are usually applied for relatively long rock tunnels and are generally very expensive to purchase. A continuous tunnel length in rock of at least 1000 to 1500 meters is usually the length where the TBM method can be considered (Banverket et al., 2002). The rock tunnel part of Allélänken is about 800 meters long, why the recommended method to use for this part of Allélänken is the conventional drill and blast method.

## 5.4.3 Tunnel sections

The measurements used in the design of Allélänken's tunnel sections are primarily based on a reference project, which is one of the tunnels in the on-going project Tvärbanan in Stockholm. Tvärbanan is a light rail that will connect the bus, metro and commuter lines around the center of Stockholm (SL, 2010). The tunnel that is used as a reference is the concrete tunnel part of the Tranebergstunneln, near the residential area Margretelund. The cross section plan for this concrete tunnel is found in Appendix IV and is designed by Ramböll<sup>11</sup>. Sketches of cross sections for Allélänken are shown in Figure 5.13 and 5.14. Larger versions of these sketches are also found in Appendix IV.

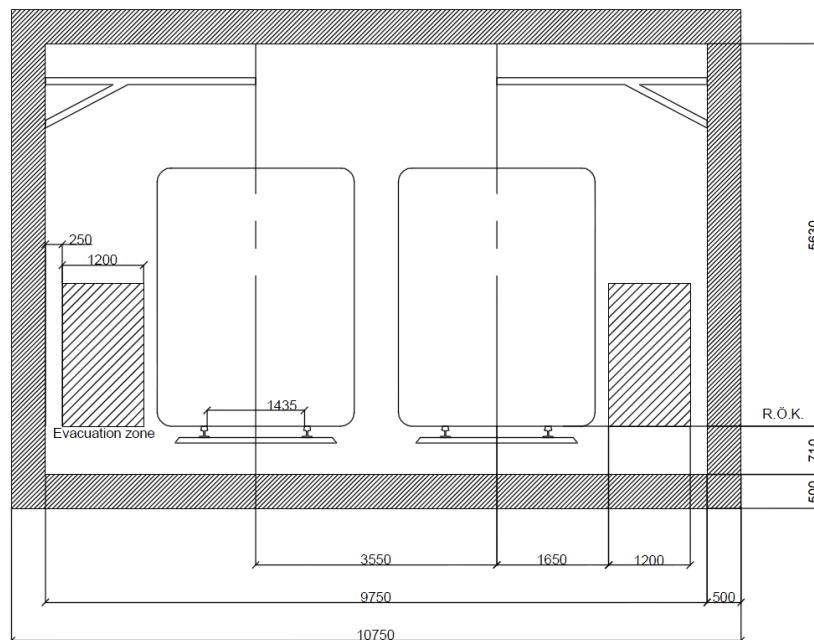


Figure 5.13 Sketch of tunnel section in between stations in Allélänken.

<sup>11</sup> Design of concrete tunnel Margretelund acquired by Tobias Tyberg (Rock engineer, Ramböll) via e-mail 2012-03-19 with permission from the client SL.

Measurements in Figure 5.13 are entirely based on the reference tunnel at Margretelund. The platform width for Allélänken's stations in Figure 5.14 is however not based on this tunnel since it does not include station platforms. The width of the platforms of 5 meters is by Rydman (2010) considered to be sufficient from a safety perspective and is a larger value than generally demanded for station platforms. Below are the design values for the cross sections.

- Track gauge: 1435 mm
- Track center distance: 3550 mm
- Width evacuation zone: 1200 mm
- Thickness concrete wall: 500 mm
- Inner height from top of rail (Station Centralstationen excluded): 5630 mm
- Total width of section in between stations: 10750 mm
- Total width of section at station: 17650 mm

The cross section at Station Centralstationen will most probably be higher since the station is planned with a mezzanine. No sketch has been done for this scenario, but the inner height from top of rail is in this case estimated to be approximately 8000 mm. The width of 500 mm for the concrete walls was by Tobias Tyberg<sup>12</sup>, rock engineer at Ramböll, considered to be an appropriate design value. The width of the cross sections has in the track design been rounded up to 11000 mm from 10750 mm and to 18000 mm from 17650 mm.

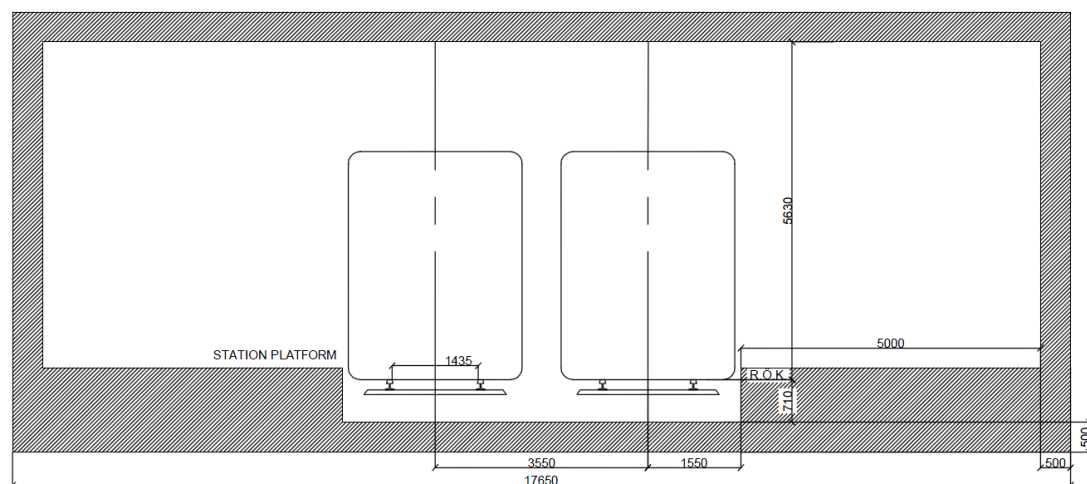


Figure 5.14 Sketch of tunnel section at station in Allélänken.

The document *BOStrab - German Federal Regulations on the construction and operation of light rail transit systems* (Hafter, 1987) is the regulations used for light rails not only in Germany, but also in other countries. BOStrab was for example used as a basis for the safety assessment of the Copenhagen Metro system (Wigger, 2001). The regulations regarding tunnels are found in §30 and comment (5) states that:

<sup>12</sup> Tobias Tyberg (Rock engineer, Ramböll) e-mail 2012-03-19

*“Tunnels must be provided with emergency exits to the open air, and be so arranged that the rescue/escape distance to the nearest platform, nearest other emergency exit or the tunnel mouth never exceeds 300 m” (Hafter, 1987).*

300 meters was also the length used in the reference project Tvärbanan in Stockholm<sup>13</sup>. The distance between the stations in Allélänken is about 550 meters. A scenario where e.g. a fire starts in the tunnel, blocking one direction, the requirements on emergency exits is thus not fulfilled. Emergency exits must hence be installed in the tunnel. In which way this can be done is recommended to be studied in further investigations.

The design of the rock tunnel section in Linnéstaden may differ from the sections proposed in this chapter. The different excavation technique of drill and blast compared to cut-and-cover, combined with the prerequisites in rock compared to clay, may result in a different design of the tunnel section at this part.

#### **5.4.4 Impacts during construction**

Interferences and impacts in the urban environment of central Gothenburg are inevitable for a project like Allélänken, where the majority of the route demands excavations in clay. The route is partially located in a park area where relatively limited impacts on existing traffic can be expected, but where the environmental impacts are more extensive. For the section of the tunnel located in the bedrock, low impacts can be expected as the excavation takes place underground. Soil excavation in developed areas where e.g. roads and railways are located results however in larger impacts during construction.

The choice of structural support for the soil excavation determines to a large extent the required use of land around the corridor during construction. The background report for Västlänken by Banverket et al. (2006c) discusses the two methods of steel sheet pile walls or diaphragm walls as retaining structures. It is stated that steel sheet pile walls generally are placed 1.5-2 meters outside the concrete construction and that the gap is refilled with soil. Diaphragm walls can however be used as a part of the permanent concrete construction, why the gap is not needed. Diaphragm walls are on the contrary generally thicker than concrete walls, why the design value of 0.5 meters for the concrete walls may have to be revised.

The required space around the corridor is of significance in some critical parts along the route of Allélänken. In the designed section at the central station, an assumption has been made that the minimum distances of 2.1 meters is used between the outer track centerlines and the tunnel walls. This distance is based on the regulations for Stockholm's subway<sup>14</sup>. If the thickness of the concrete walls is greater than the design value of 0.5 meters, another solution for this section is required. A possible addition of 1.5 meters during construction at the section is illustrated with blue color to the left in Figure 5.15. The proposed design of this section in scale 1:1000 is found in Appendix VI. Another section where the width of the corridor is of great importance is the section at Hagabion, shown to the right in Figure 5.15. As the excavation in this

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<sup>13</sup> Tobias Tyberg (Rock engineer, Ramböll) e-mail 2012-05-23

<sup>14</sup> Cedric Hanneberg (Railway engineer, Ramböll) e-mail 2012-03-07



section may be relatively deep (elaborated further in Chapter 5.5), adjacency to Hagabion as well as buildings along Linnégatan should be avoided.

Polhemsplatsen is today an area with heavy traffic and where the space for the corridor of Allélänken is relatively limited. Appropriate rerouting of car and tram traffic will be necessary in the area and the flyover Bangårdsviadukten should not be located further east in order to enable the proposed corridor. In addition to this, the river Fattighusån south of Polhemsplatsen will require a temporary disassembling. Polhemsplatsen is thus significantly affected during the construction of Allélänken.

Major traffic rerouting will also be necessary in the area around Järntorget, as the area today is very frequented by trams and buses. The proposed route also conflicts with tram and car traffic along the northern part of Linnégatan. No space beside the excavation at Linnégatan can be used for temporary traffic due to the limited space between the houses. A satisfying solution for the traffic rerouting in these areas will thus be of great importance during the construction of Allélänken. Appropriate measures also have to be done in order to reroute the flow of water in the culvert beneath Linnégatan, previously mentioned in Chapter 5.2.3.

The streets Nya Allén and Parkgatan will as well require traffic rerouting. To which extent this has to be done is dependent on the choice of route in the area. If the park area in between the streets is used for the corridor, traffic on the streets could be maintained in some parts. If the corridor mainly is located along the street Nya Allén rerouting of traffic is required to a higher extent. This is an alternative design discussed in Chapter 5.6.

Appropriate measures also have to be done to minimize noise and vibrations levels during the construction. This mainly applies to the area along the densely built-up Linnégatan where vibrations have to be kept to a minimum in order to prevent damages to the adjacent buildings. The environmental impacts during construction are elaborated in Chapter 6.3.

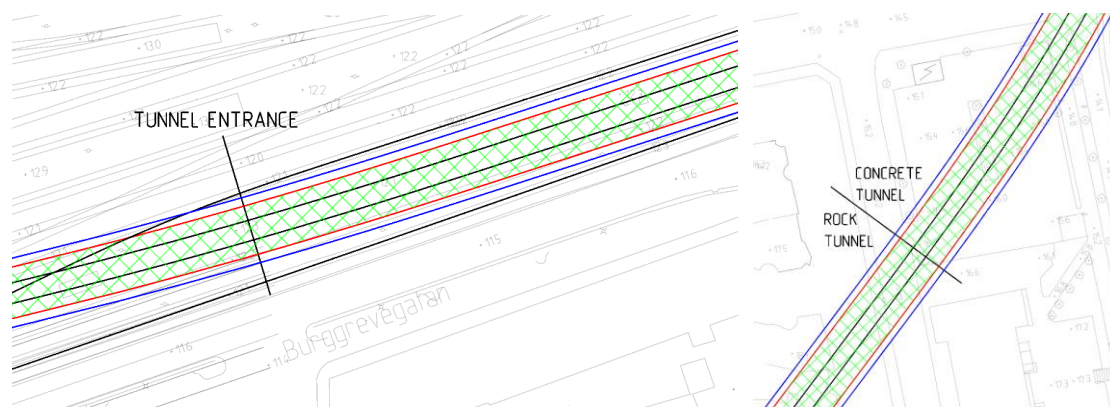


Figure 5.15 Illustrations of the addition in width of 1.5 meters, marked with blue color, needed when using steel sheet pile walls as structural support.

## 5.5 Land use

In order for Gothenburg to enable a future development of the tram network centrally, undeveloped areas of interest for the public transportation need to be reserved. An example of such a reservation of land in the past is the area along the river Göta älv, Södra älvstranden. Götatunneln aimed at removing the heavy traffic from the road E45 and in this way connect the city to the water. Development of the highly attractive area along the river has since the completion of Götatunneln in 2006 been on hold. This has been made in order to enable the construction of the Västlänken project, which in this area requires wide excavation pits in the clay. The same kind of planning should be applied for mainly three areas in Gothenburg to enable the proposed route of Allélänken.

The largest area of interest is naturally the area along Nya Allén. This park area enables the centrally located proposed route that most probably would not be possible to design anywhere else in central Gothenburg, at least not to the relatively moderate expected costs and the favorable conditions it provides. A reservation of this land is thus necessary to enable the proposed corridor.

The second area that needs to be considered is Polhemsplatsen. As been told previously in this chapter, the planned flyover Bangårdsviadukten requires an extensive interference in the area. The planned route of Allélänken is located just east of Bangårdsviadukten and development of this area should be kept to a minimum in order to enable the proposed route of Allélänken.

The third area of interest is the site north of the cinema Hagabion, today consisting of a parking lot. The site has since 1992 been possessed by the city-owned housing corporation Poseidon, which are planning to build three houses with a total of 60-80 apartments at the site (Boplats.se). The relatively small area is of great importance for the proposed route of Allélänken. As previously shown in Figure 4.2 the bedrock slopes down quite steeply towards Linnégatan in this area. The site enables today, with the removal of the parking lot, an entrance to the bedrock at a depth of approximately 5-10 meters. If the site is developed as planned, the excavation along Linnégatan has to be significantly deeper in order to reach the bedrock before the houses. This may rule out the proposed route of Allélänken. If a deeper excavation is possible it will most certainly be technically very difficult in the narrow area along the street and may also pose a risk to the adjacent buildings along Linnégatan. Development of this site is thus recommended to be done after the possible completion of Allélänken.

## 5.6 Alternative designs

Prior to the design of Allélänken presented in this thesis, a number of different alternative designs were considered. The alternative with the highest potential of replacing the proposed design is the alternative of excavating along the street Nya Allén instead of in the park. The obvious advantage of this alternative is that the environmental impact in the park area between the streets would not be as extensive as in the proposed design. The four tree lines running along Nya Allén would however most probably need to be felled due to the width of the corridor. This negative environmental impact is not as extensive as in the proposed design, as the tree lines are affected less. Another negative impact with the alternative of excavating along the street is that the car traffic along Nya Allén cannot be maintained during the

construction time. In the proposed design the traffic can be maintained to a higher extent as the corridor to a large part is located in the park. It is also easier to construct tracks with favorable geometry in the proposed design compared the alternative, as the width of the park area enables this to a higher degree.

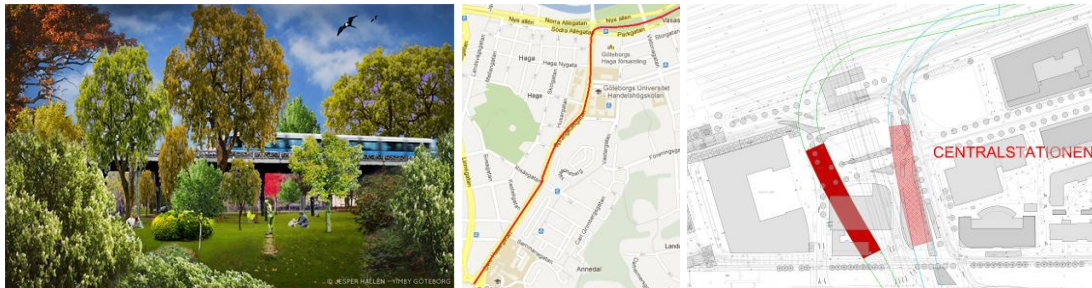


Figure 5.16 From the left; Suggestion by Hallén (2011) of elevated tracks along Nya Allén, Sprängkullsgatan/Övre Husargatan (Google Maps, 2012 (edited)) and an alternative position of Station Centralstationen.

To construct an elevated tramway is a way of receiving similar benefits as with a tunnel, but often to a lower cost. The tram traffic is grade separated from the traffic below and can be operated with a high capacity and speed. The primary disadvantages of this solution are the interferences it brings in the city environment. The negative effects are, just as with street running tracks, the noise created and the visual impact it brings (Hallén, 2011). These factors can also be enhanced as a result of the elevation. An elevated tramway would in addition to this most likely not be applicable along Linnégatan. An illustration of an elevated tramway along Nya Allén by Hallén (2011) is shown to the left in Figure 5.16. To construct street running tracks along the same route would not result in the benefits that a grade separation construction brings and would also result in larger permanent environmental impacts.

An alternative to the rock tunnel construction in the proposed design would be to construct a cut-and-cover tunnel the entire distance along Linnégatan. As previously mentioned, concrete tunnels generally are five to ten times as expensive as rock tunnels (Banverket et al., 2006b). This fact combined with the mentioned culvert running along the street and the increased demand of traffic rerouting makes the rock tunnel alternative more favorable. Future extensions possibilities are also easier to implement from within the bedrock.

Instead of using Linnégatan as a connection to Linnéplatsen the streets *Sprängkullsgatan* and *Övre Husargatan*, as shown in the middle of Figure 5.16, could be used for a concrete tunnel construction. Considering that Järntorget is a very important junction point and highly suitable for future extensions, this alternative was rejected in an early stage.

An alternative location for Station Centralstationen, shown to the right in Figure 5.16, was also considered. The location was west of Bangårdsviadukten, instead of east as in the proposal. The west location was however proven to be less favorable as it resulted in smaller radiuses of the tracks and was also more adjacent to both Bangårdsviadukten and Trädgårdsföreningen.

## 5.7 Future extension possibilities

Allélänken should not be seen as a complete solution for the capacity issues in the long run. A future increased demand of public transportations will require a capacity strong and well-planned central grade separated network in Gothenburg. Extensions of Allélänken could e.g. enable the K2020 vision of the large beltway structure Storkringen, previously shown to the left in Figure 2.4. Suggestions on possible extensions of Allélänken are shown below in Figure 5.17.

Extensions 1-3 could realize the west connection to Hisingen in Storkringen through an immersed tunnel. The first suggestion diverge north at Järntorget whereas the second and the third continues to Masthuggstorget where a connection to Hisingen is made, much like the sketch of Storkringen in Figure 2.4. Extensions can e.g. be made via the street *Första Långgatan* through a cut-and-cover tunnel or as in the third suggestion, via a rock tunnel. Since rock tunneling is significantly less expensive and also creates fewer impacts in the city compared to concrete tunnels, extension 3 should be considered the most appropriate.

An extension south (4), also this according the Storkringen vision, towards Sahlgrenska and Korsvägen is another possibility. Tram traffic on the future flyover Bangårdsviadukten (5) should also be considered as this could create an east connection to Hisingen. A possible connection could also be to extend the tunnel further east and eventually enter the bedrock as seen previously in Figure 4.2.

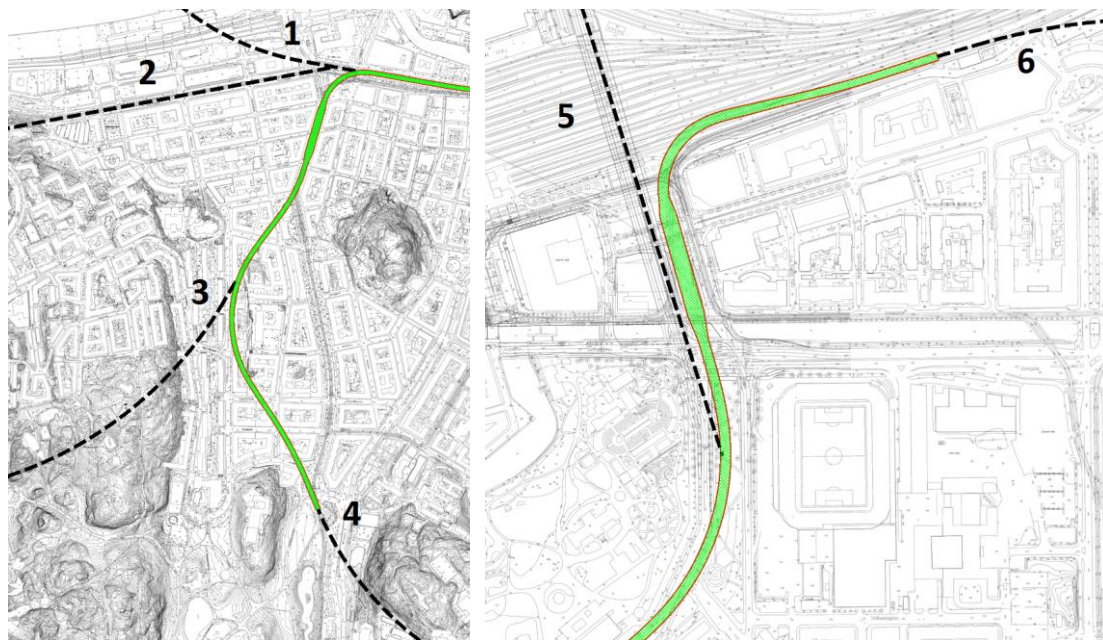


Figure 5.17 Possible future extensions for Allélänken.

## 6 Analysis

This chapter aims at analyzing the results from six different aspects. These are *Cost estimate*, *Social impacts*, *Environmental and cultural impacts*, *Travel time*, *Potential unburdening of Brunnsparken* and *Capacity*.

### 6.1 Cost estimate

One of the factors that previously have been mentioned as one of the main advantages of Allélänken is the relatively limited expected cost. This expectation was mainly based on the facts that the tunnel can be located shallowly and that no buildings were in the way of the proposed corridor. In order to make a proper cost calculation for Allélänken more detailed investigations are however required. This chapter provides instead estimates done by a number of participants of an internationally assembled tunnel group within Ramböll.

The proposal of Allélänken was presented together with supervisor Patrik Sterky at a meeting with the tunnel group at Ramböll's office in Gothenburg April 20<sup>th</sup>. The discussion afterwards focused mainly on the potential cost of the project, where  $350 \pm 100$  million euros ( $\approx 3,5 \pm 1$  billion SEK) by the group were considered a reasonable sum. In order to get the estimated cost for the project more specified, a questionnaire was sent to the participants. It contained the following information:

- *The tunnel is 3.5 km long whereof 2.7 km concrete tunnel in clay and 0.8 km rock tunnel. We think that excavation in the clay can be made quite shallowly at a depth of 7-8 meters, since no buildings are located within the corridor of the tunnel. The width of the corridor is about 11 m.*
- *The number of stations is four. Length of each station is 110 m and width about 18 m. One of the stations will be located at a depth of about 10 meters and contain a mezzanine. The others shallowly at 7-8 m.*
- *A majority of the route in clay is located in a park and no demolitions or reinforcements of existing buildings will hopefully be necessary. Because of this, we believe that the project wouldn't have to be as expensive as many other tunnels located in an urban environment with clay. What do you think?*

The participants of this questionnaire are Susanne K. Pedersen (Client Liaison Officer, Ramböll Denmark), Per-Erik Söder (Rock engineer, Ramböll Sweden) and Peder Thorsager (Division manager of Rock engineering, Ramböll Sweden). The feedback is compiled in Table 6.1 and the participants (A-C) are presented in no particular order. Costs are presented in the price level of 2012.



Table 6.1 Estimated costs for Allélänken in millions of Swedish crowns (MSEK).

	Con. tunnel	Reinforcement	Rock tunnel	Stations	Other	Total
A						3000-5000*
B	350	350	48	400	800	1948
C	600-800		200-300	800-2000	1000	2600-4100

*\*The estimate is made under the assumption that no major relocation of roads and utilities is required. As construction costs tends to increase rather than decrease a reasonable figure is 3500 -500/+1500 million SEK – Participant A*

The total costs are thus estimated to 1948 – 5000 billion SEK. The costs for the specific tramway construction, *BEST (Bana, El, Signal, Tele)* in Swedish, are not included in these estimations. These costs amounted to about 6 percent for the chosen route of Västlänken (Banverket et al., 2006i), why the same percentage can be assumed also for Allélänken. An appropriate restoration of the park area along Nya Allén is not included in the estimations either. A total increase of 10 percent is thus assumed with BEST and restoration included. The estimated cost is thus 2143 – 5500 billion SEK, which correspond quite well with the initial estimation of 3,5±1 billion SEK.

## 6.2 Social impacts

In which way to measure social impacts as a result of a new infrastructure investment is not standardized and no established methodology for these impacts exists. It is today a term that can be interpreted and applied in various ways (Banverket et al., 2006h). In a report by Almar (2008) concerning the planning of Copenhagen’s metro system, the term social impacts is described and is quoted below.

*“There are a lot of social impacts when a new infrastructure is developed. These impacts mean transformations, not only physical changes, but also in the economy, lifestyles and so on. These transformations are the consequences of the new infrastructure, which is constructed due to the different aims, such as town-planning, economic, political and social objectives.”*

The previously mentioned background report by Banverket et al. (2006h) concerning social consequences for the Västlänken project focuses mainly on these five questions;

- How will the city life change?
- In which way is security issues in the city affected?
- Are their certain groups of people who will gain from the investment?
- Will a specific gender gain from the investment?
- Will a possible city expansion affect the segregation in the city?

Allélänken is a project implemented in an existing tram network in an already developed urban environment. The social impacts may thus not be of the magnitude of e.g. Västlänken or the Copenhagen metro, but will nevertheless be of importance in the analysis. The questions above will be used as a basis for this chapter.

Chapter 5.2 presented the proposed station locations along with illustrations showing the influence area for each station. The entire set of spheres of both the 400 meters/5-minute walking distance and the 800 meters/10-minute walking distance is shown in Figure 6.1. The 10-minute sphere covers the majority of the area that is considered as central Gothenburg. The highly attractive area within the old moat is included where among other things the shopping center *Nordstan* with nearly 30 million visitors annually is located (Banverket et al., 2006f). The spheres also cover important junction points as the Gothenburg central station, Drottningtorget and Brunnsparken.

The sphere of 400 meters/5-minute walking distance were in Chapter 5.2 considered to be the more appropriate indicator of the two distances, since the willingness to move most probably is lower for travellers by tram than for trains. To sum up the reasoning in Chapter 5.2, the stations of Allélänken will have good connections to the important junction points Gothenburg central station, Drottningtorget, Hagakyrkan and Järntorget. Attractive areas such as Kungsporsavenyen and Linnégatan are also included in the influenced areas as well as many dense populated residential areas.

All four stations are located in an urban area with an existing city structure why further substantial development in these areas must be considered unlikely. Exceptions can be made for the area Södra Älvstranden north of Station Järntorget and the area Gullbergsvass north of Station Centralstationen that are reserved for residential development. Station Järntorget and Station Centralstationen are today located in existing important junction points that offers good transfer possibilities. The area at Station Haga consists today of a station frequented by several tram and bus lines. The station is today not an important junction point but has good possibilities of developing into one as a result of Västlänken, when 30 000 travellers per day are expected to depart or arrive at the station (Banverket et al., 2006h). Station Avenyn is located in an attractive area that by GR et al. (2009) is considered to be an important future junction point.

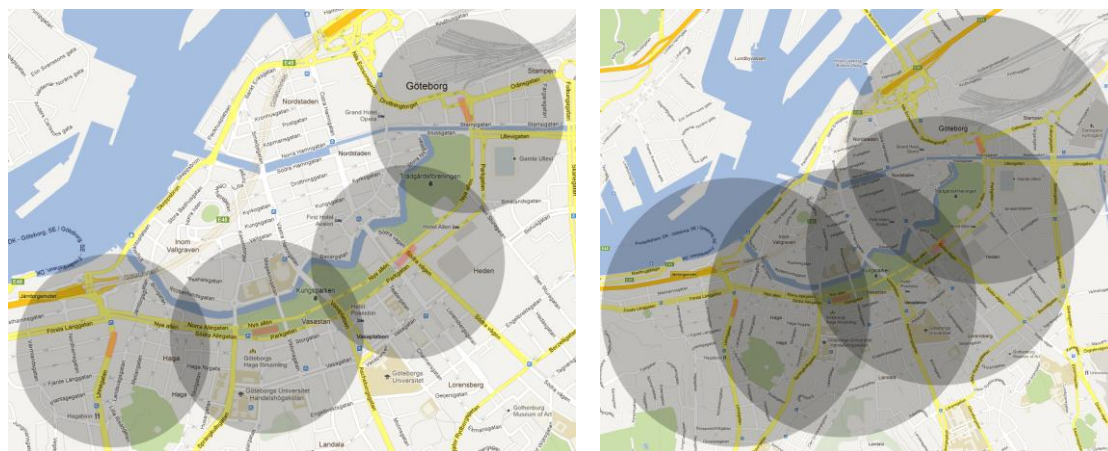


Figure 6.1 The areas influenced by Allélänken's station with 5 minutes walking distance to the left and 10 minutes to the right (Eniro, 2012 (edited)).

Underground stations have in many ways a positive effect when it comes to safety issues. They are protected from the sometimes harsh Nordic weather and also protect from the possible traffic over ground. Underground stations can however often be perceived as inhospitable and unsafe. A way to avoid this is to keep the pedestrian underpasses as short as possible as they feel insecure, especially at nighttime when the flow of people is low (Banverket et al., 2006h). Another way to prevent the feeling of confinement is to allow as much daylight into the stations as possible. In the case of Allélänken, this could be done in a similar way as Figure 5.8 shows. This should be applicable at the stations at Avenyn and Haga, but will probably be more problematic at Centralstationen and Järntorget where the superjacent areas today to a high extent are areas developed by roads and tramways.

The primary aim of Allélänken is to unburden the central parts of the network, especially Brunnsparken, and increase the capacity of the network. The chosen corridor is located outside what today is considered to be the most central parts of Gothenburg where many attractive destinations are situated. The previously mentioned report by Almar (2008) concerning the planning of Copenhagen's metro system discusses the effects of the new metro line in the just recently developed Ørestad district. The presence of the new metro line was in this report considered to *"help to develop the mobility and will link the new town with the city center"*. The aim of the Copenhagen metro was much like Allélänken to reduce the travel times and reduce the congestion problems in the city center.

The same prerequisites do not entirely apply in the case of Allélänken, since it is implemented in an already developed city center. Similar effects as a result of a new infrastructure investment can however be expected also in the case of Allélänken. Good transport possibilities to a certain area make it more attractive and attractive areas will also affect the number of travellers (Banverket et al., 2006h). Both Västlänken and Allélänken have thus the power of changing the way we look at central Gothenburg. The need of arriving or departing at Brunnsparken may thus not be as great in the future Gothenburg as it is today.

The implementation of Allélänken in Gothenburg's tram network reduces the travel times centrally, but travel times will still be the same in the outer areas. On the condition that an extension of existing platforms are made, the capacity will however increase along the entire stretch Angered/Bergsjön to Tynnered since significantly longer tram sets than today can be used. How these facts will affect aspects as which groups of people that will benefit from the investment or how it can affect the segregation in the city is unclear. The effects of Västlänken regarding these aspects stated that the project would first and foremost benefit groups of people that had no access to a car, where women and younger people are mostly represented. The residential segregation was in the same background report by Banverket et al. (2006h) expected to increase slightly as a result of the increased attractiveness of the central area. The expected expansion of the city as a result of Västlänken will however provide possibilities for different groups of people to interact and find their place in the city, the report states. If a similar effect can be expected from Allélänken is unclear, but the mentioned facts at least give a hint on the potential social effects of such an infrastructure investment in a city.

### 6.3 Environmental and cultural impacts

One of the advantages of the proposed corridor is the minor impact it has in terms of demolitions and reinforcements of existing structures. The stretch has however a significant environmental impact, mainly in the park area along Nya Allén. Also places of cultural significance are affected by the choice of corridor. The areas that are affected by Allélänken based on these two aspects are described in this chapter. The identified areas are shown below in Figure 6.2.

Fattighusån (C1) is a canal that connects *Mölnålsån* in the east with *Stora Hamnkanalen* in the west. It was opened already in 1641 and was the place where first inhabitants in Gothenburg could get their drinking water (Wirsin, 2001). During construction of Allélänken the brick walls of Fattighusån have to be disassembled and then restored when the tunnel construction is finished. The required blockade of water flow should not cause major disruptions in the water level of Stora Hamnkanalen since it also is connected to the old moat. In conclusion, the negative effects can be considered as low as long as a satisfactory restoration of the brick walls is made after construction.

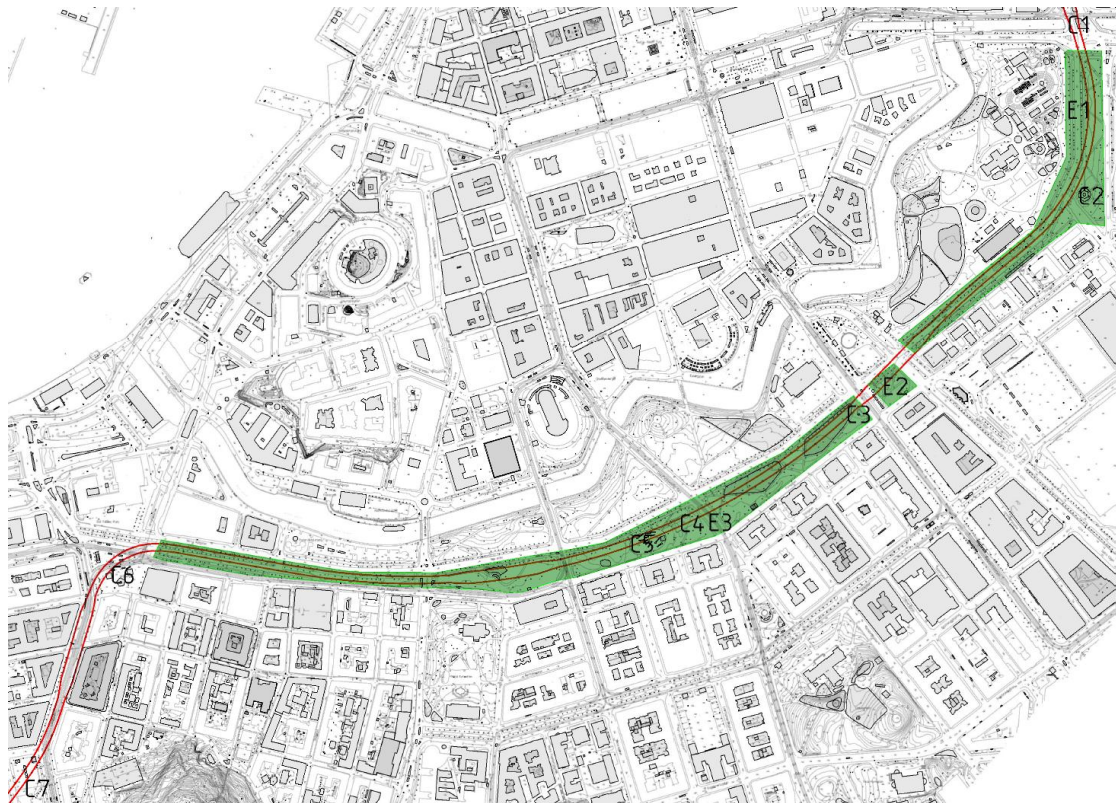


Figure 6.2 Environmental (E) and cultural (C) areas affected by Allélänken.

Kungsparken's eastern part (E1) runs along Nya Allén and Trädgårdsföreningen. Except for the tree lines along Nya Allén, the area also holds a few larger trees and the statue *Polhemsmonumentet* (C2). In the background report by Banverket et al. (2006e) concerning parks and natural environments for the Västlänken project the recreational value for the area is considered to be low, whereas the nature values are ranked as medium. The corridor of Allélänken mainly affects the park in the northern



part of the area and mainly the avenue with its tree lines in the southern part. Polhemsmonumentet is not in the way of the chosen corridor, but could be affected if a different geometry of the tunnel would be applied. The proposed corridor means no intrusion in the park Trädgårdsföreningen that is protected as a heritage building and where no trees are allowed to be felled (Banverket et al., 2006e).

*Charles Felix Lindbergs plats* (E2) is a small park area confined by Kungsportsavenyen and Södra vägen and consists mainly of Nya Allén's tree lines, some larger single trees, several benches and the statue of Charles Felix Lindberg. The corridor of Allélänken is primarily located along the tree lines of Nya Allén, but also affects some larger single trees. The statue is adjacent to the corridor but should not be affected unless the location of Station Avenyn is relocated further south.

The statue of *John Ericsson* (C3) is not located within the proposed corridor. It is however located approximately 6 meters from the border of the corridor, why the statue may have to be temporarily relocated during the construction time if the location or width of the corridor is revised.

The part of Kungsparken marked E3 in Figure 6.2 is an area where major environmental impacts can be expected as a result of Allélänken. As mentioned in the beginning of Chapter 5, an intrusion in the part of Kungsparken confined between the streets Nya Allén and Parkgatan is a prerequisite for the proposed route of Allélänken. The alternative of using the street Nya Allén for the corridor would, as told in chapter 5.6, most probably result in the complete removal of the four tree lines along the street and would not provide the same prerequisites for a good horizontal alignment of the tracks.

A significant part of the trees affected in area E3 are old and majestic and have probably been around since the planting in the 19<sup>th</sup> century, as previously told about in Chapter 5.2.2. Although the environmental impact in the area has to be considered as major, the larger trees are planted sparsely which may imply that a fairly limited number of trees have to be felled. How many trees that have to be felled as a result of Allélänken and the exact extent of the environmental impact in the area are not further investigated in this thesis.

Besides the plantation in the area E3, the statue *Ägget* (C4) and a miniature golf course (C5) are also found, shown in Figure 6.3. Both will be located in the corridor of Allélänken and will be forced to relocate during construction time and possibly installed again after the construction is finished.

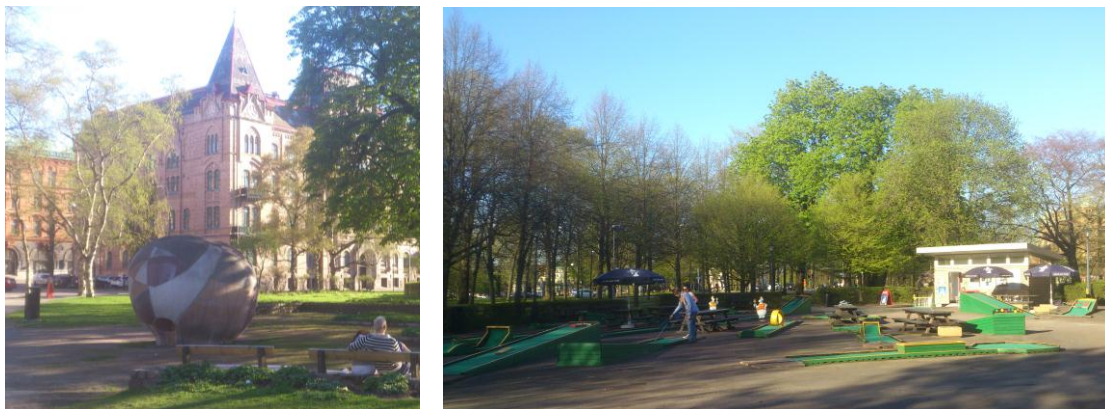


Figure 6.3 "Ägget" and the miniature golf course in Kungsparken.



The things of cultural significance at Järntorget (C6) are mainly the square itself and the statue *Järntorgsbrunnen*. The route of Allélänken makes a minor intrusion in the square and passes through the small building today occupied by Pressbyrån. A smaller radius of the curve at Järntorget would decrease the intrusion at the square but would at the same time worsen the geometry of the tracks and decrease the maximum allowed speed. The building *Hagabion* (C7) was built in 1875 and is today used for various purposes besides cinema (Domellöf-Wik, 2009). The proposed corridor is not located within the premises of the building, but reinforcements to some extent will probably be necessary as the corridor is located as close as 4 meters in the proposal.

## 6.4 Travel time

In order to calculate the travel time between Polhemsplatsen and Linnéplatsen a simulation of the traffic in the tunnel is needed. This is a part that is not included in this thesis. A reasonable travel time can however be acquired by a comparison with e.g. Stockholm's metro with an equal distance, number of stations and similar geometry of the tracks. The distance between the metro stations *T-Centralen* and *Skanstull* on the green line is about 3.2 kilometers and includes five stations (Eniro, 2012). The same prerequisites apply for the distance between Allélänken's Station Centralstationen and Linnéplatsen, given that the current station at Linnéplatsen remains its position. The travel time between the two stations in Stockholm is five minutes (SL Reseplanerare). Considering the relatively sharp curves at Järntorget and Station Centralstationen in the proposal of Allélänken, a travel time of about six minutes can be expected between Station Centralstationen and Linnéplatsen. The same distance by tram takes today 15 minutes (Västtrafik, 2012). An addition of about one minute to this time is needed since Drottningtorget and Polhemsplatsen, where Station Centralstationen is located, is about 350 meters apart (Eniro, 2012). The travel time with Allélänken can thus be expected to be reduced from today's 16 minutes to 6 minutes.

The total distance from Angered to Tynnered by tram is 22.8 km (Eniro, 2012). The distance by tram takes today 50 minutes, time for interchange excluded. With Allélänken the travel time would be about 40 minutes that result in an average speed of 34.2 km/h. This can be compared to the average speed of the three metro lines in Stockholm: Green ~ 30 km/h, Red ~ 35 km/h and Blue ~ 40 km/h (M Larsson).

## 6.5 Potential unburdening of Brunnsparcken

The primary goal of Allélänken is to increase the capacity of the tram network and unburden Brunnsparcken by redistributing traffic to Allélänken. To which degree Brunnsparcken can be unburdened is dependent on the amount of trams that make use of the tunnel. This chapter aims at providing a picture of the future situation in Brunnsparcken in terms of capacity by presenting three different scenarios for the year 2030. The three scenarios are:

- Scenario 1 - Operalänken unburdens Brunnsparcken by 25 %. No Allélänken.
- Scenario 2 - Operalänken unburdens Brunnsparcken by 25 %. Allélänken is operated by tram lines 1 and 7.
- Scenario 3 - Operalänken unburdens Brunnsparcken by 25 %. Allélänken is operated by tram lines 1, 7, 9 and 11.

As previously mentioned, Operalänken cannot be built before the completion of Västlänken. Operalänken aims at creating a centrally located optional route along the river Göta älv in order to unburden Brunnsparcken. To which degree this can be done has however not yet been investigated. In these three future scenarios the share of tram traffic Operalänken reroutes from Brunnsparcken has been assumed to be 25 percent.

Table 6.2 below is based on the report and simulation by Ramböll (2011) on the future situation in Brunnsparcken, where buses were relocated in order to free space for trams. The figures for scenario 1 and 2 are also based on a compilation of data made by Västtrafik (2011) that showed number of trips per year for each of the current tram lines. The chart by Västtrafik showed that tram lines 1, 7, 9 and 11 stood for respectively 12, 10, 8 and 10 percent of the total tram traffic in Gothenburg. This distribution has been assumed to remain for the future scenarios as well. In Table 6.2, the different tram stops (A-F) in Brunnsparcken are viewed in the rows. The first (I) column represents the number of trams departing per hour from the stop and the second (II) represents the number of buses departing per hour. The third (III) represents the loading rate for each stop.

According to the publication by Trafikverket named *VGU – Vägar och gators utformning* (Design of roads and streets), the risk of overloading stops can be categorized as following (Ramböll, 2011):

- Low risk < 50%
- Medium risk 51-60 %
- High risk > 60%

Table 6.2 The loading rate for tram stops in Brunnsparcken.

	Present			2020			2030		
	I	II	III	I	II	III	I	II	III
A	13	25	39%	18	8	32%	27	12	48%
B	13	28	41%	18	8	32%	27	12	48%
C	20	20	44%	36	12	60%	54	18	90%
D	20	20	44%	36	20	67%	54	30	101%
E	33	12	56%	36	20	67%	54	30	101%
F	33	12	56%	36	12	60%	54	18	90%

	Scenario 1			Scenario 2			Scenario 3		
	I	II	III	I	II	III	I	II	III
A	20	12	36%	16	12	28%	12	12	22%
B	20	12	36%	16	12	28%	12	12	22%
C	41	18	68%	32	18	53%	24	18	41%
D	41	30	75%	32	30	59%	24	30	45%
E	41	30	75%	32	30	59%	24	30	45%
F	41	18	68%	32	18	53%	24	18	41%

The figures for the present situation and in 2020 are directly acquired from the report by Ramböll (2011). Despite the fact that Brunnsparken by Kent Lindahl at GS Spårvagn is described as being overloaded already today, the loading rate for the majority of tram stops in Brunnsparken is denoted with a low risk. In year 2020, as mentioned previously in Chapter 5, the congestion in the area is expected to increase although buses were removed from Brunnsparken.

An assumption is that the expected increase of one way trips between 2020 and 2025, previously presented in Figure 3.3 in Section 3.3, also applies between 2025 and 2030. This gives an increase of 114.8 million trips per year from 2020 to 342.7 million trips per year in 2030, which correspond to an increase of about 50 percent. With an assumption that this number also apply to the traffic in Brunnsparken, the majority of stops in Brunnsparken run a very high risk of being overloaded in 2030 as seen in Table 6.2.

Scenario 1 assumes that Operälänken unburdens Brunnsparken by 25 % by 2030. With the assumptions made, the result is that the majority of stops run a high risk of being overloaded. Scenario 2 and 3 on the other hand make use of Allélänken. Tram line 7 already today operates on the route Bergsjön – Tynnered. Tram line 9 and 11 also operates in the north-eastern network but continue however towards Saltholmen in the west, why a connection to existing network for these tram lines along Första långgatan is assumed in Scenario 3. Tram line 1 originates from Östra Sjukhuset in the east and is assumed to connect to Angeredsbanan near Svingeln.

Line 1 and 7 answer to 22 percent of the total tram traffic. With these lines operating on Allélänken in 2030 as in Scenario 2, the situation in Brunnsparken can be expected to be similar to today with low to high risks. Line 1, 7, 9 and 11 answer to 40 percent of the total tram traffic. In scenario 3, this result in a more favorable situation than today, with low risks of overloading for every tram stop in Brunnsparken. It should be said though, that the decreases of loading rate in the scenarios are in direct correlation to the assumed decrease of traffic. This relation is not entirely the case in the report by Ramböll (2011), why the relation between the number of departures per hour and the loading rate may differ between the presented scenarios and the data acquired from the report.

These scenarios assume that the tram lines in the network operate on the same routes as today. As a result of a development in the city, these prerequisites may change just like it has in the past. In order to enable these calculations, the use of the current 30 meters tram sets is assumed. Allélänken is planned for longer tram sets with higher capacity why a larger decrease of the loading rates in Brunnsparken could be acquired. In spite of the many assumptions required, the scenarios presented provide an overview of the potential effects Allélänken could have on the capacity situation in Brunnsparken.

## 6.6 Capacity

One of the aim with Allélänken is that the stretch Angered/Bergsjön – Tynnered can be operated with tram sets longer than the current standard of 30 meters. As told before in Chapter 3.2, parts of the Gothenburg network has previously been operated by 45 meters long trams prior to the Kringen project. Angeredsbanan was operated by even longer tram sets in the 1970's when tram sets up to 60 meters was used (Ekeving, 2008). Today only a few stations platforms in the network are adapted to

longer tram sets<sup>15</sup>. Among these may be mentioned the underground station in Hammarkullen and Hjällbo station with its approximately 110 meters (Eniro, 2012).

In order to enable traffic with longer tram sets on Allélänken, reconstruction of the majority of the existing stations towards Angered/Bergsjön and Tynnered is needed. As previously told in Chapter 5, investigations by Trafikkontoret showed it would be very hard to extend the existing tram platforms centrally because of the relatively densely built-up city structure. The prerequisites for the outer parts of the network are however more favorable. The tracks run on embankments that for the most parts are separated from other traffic and the city is not as densely built-up as in the city center. No analyses have been made for the extension possibilities for each station towards Angered/Bergsjön and Tynnered. A visual inspection shows however that extensions of the majority of platforms should be possible without major constructional difficulties or great costs.

The choice of 110 meters platforms in Allélänken is, as previously told, a preparation for future needs more than a design for the needs of today. Initially it is more likely to double link the existing trams to sets of 60 meters, which also may be a reasonable length for the initial extension of existing platforms that has to be done. The light rail regulations in BOStrab (Hafer, 1987) states that “trains which form a part of road traffic, must not exceed 75 m in length”. The majority of the studied tracks run on embankment separated from other traffic. There is however a part between *Gamlestadstorget* and *Kviberg* on the leg to Bergsjön which consists of street running tracks, as seen in Figure 3.1. 75 meters is thus a reasonable length to consider for capacity calculations, besides the mentioned 60 and 110 meters. Below in Table 6.3 the capacity for a number of different lengths of tram sets are viewed. Also included is the capacity of the Allélänken tunnel based on varying headway times. The length of 45 meters, which previously has been used as a tram formation in Gothenburg, is also included in the table as well as the present length of 30 meters. Note that the numbers in the table refer to the capacity in one direction in the tunnel.

*Table 6.3 The capacity in number of persons per tram set and also per hour in relation to different headway times for the tunnel with signal system. The numbers apply to travellers in one direction in the tunnel.*

<b>Length</b> <b>Capacity</b>	<b>30 m</b>	<b>45 m</b>	<b>60 m</b>	<b>75 m</b>	<b>110 m</b>
One tram set	179	269	358	448	656
150 sec headway (24 trams per hour)	4296	6444	8592	10740	15740
100 sec headway (36 trams per hour)	6444	9666	12888	16110	23610

<sup>15</sup> Peter Rydén (Project leader, Trafikkontoret) e-mail 2012-05-15

The capacity of the tram sets is based on the current model M32 which is 30 meters long and holds 156 standing and 82 sitting passengers, giving a total capacity of 238 passengers (AnsaldoBreda, 2012). M32 is however only registered for 96 standing and 83 sitting passengers in Gothenburg, giving a total capacity of 179 passengers. There is also a limit for M32 at 140 passengers which is the “comfort capacity” (Gustafsson et al., 2012). 179 passengers is however the capacity which is used as a base in Table 6.3. Headway times are depending on the type of signal system used and for how long time a tram stand still at a station<sup>16</sup>.

The majority of the Gothenburg tram network is today operated by driving on sight, i.e. the driver of the vehicle keeps appropriate distance to the vehicle ahead based on the visual distance. Driving on sight is however not permitted in tunnels why a signal system is required (Hafta, 1987). In Gothenburg signaling systems are found in e.g. Chalmerstunneln and Hammarkulletunneln.

The rather new signal system used on the green line in Stockholm’s subway is designed a headway time of 90 seconds, i.e. the minimum time required between vehicles. Today the headway time on the green line is 120 seconds and is planned to be reduced to 100 seconds to increase the frequency. A reasonable headway time in Allélänken with an efficient signal system should be about 100 seconds<sup>15</sup>, which is a time used in the capacity table above. A headway time of 150 seconds has also been evaluated as the actual headway time in the tunnel may be higher initially.

In order to investigate if the future scenarios presented in Chapter 6.4 is possible in terms of capacity, the following prerequisites are assumed:

- 60 meters tram sets are used as this is considered as a reasonable length initially on Allélänken.
- An efficient signal system is assumed which gives a headway of 100 second and 36 trams per hour.
- The tunnel is operated 16 hours per day.
- The total expected number of trips by trams in Gothenburg was in Chapter 6.4 estimated to 342.7 million trips per year in 2030. This corresponds to about 940 000 trips per day or 470 000 trips per day in one direction.

If Allélänken is operated with these prerequisites, the tunnel can handle about 44 percent of the total tram traffic by the year 2030 according to the calculation below:

$$\frac{\text{Max capacity (people per direction and hour)} * \text{Hours}}{\text{Total number of trips per day one direction}} = \frac{12888 * 16}{470000} \approx 43,9\%$$

Scenario 3 in Chapter 6.5 was the scenario where a large amount of tram traffic was relocated from Brunnsparken to Allélänken. The scenario assumed that tram lines 1, 7, 9 and 11, which corresponded to 40 percent of the total tram traffic, operated on Allélänken. Based on the calculations above, Scenario 3 could be applicable on Allélänken by 2030. There are however many assumptions and uncertainties on data.

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<sup>16</sup> Cedric Hanneberg (Railway engineer, Ramböll) e-mail 2012-05-23



With longer headway, another distribution of tram traffic or another length of tram set the result would be different. This result should hence be seen as a pointer on the potential capacity of Allélänken rather than as the actual expected capacity.

## 7 Discussion

The purpose of this thesis was to study the prerequisites and the possibility of constructing the proposed tramway tunnel. The purpose was also to suggest a design and to study the potential generated effects and analyze these from appropriate aspects. The outline of the thesis can thus be compared to the outline of a pre-study, where similar contents often are included. In comparison to a possible future pre-study of the relatively large infrastructure project that is Allélänken, this thesis is far more limited in its format. As mentioned in the introduction, this thesis should thus be considered as an initial study rather than an actual investigation.

The most difficult decision to make in the track design was the choices of either locating the corridor in the park area in between the streets Nya Allén and Parkgatan or along Nya Allén. Although the design suggests a location in the park area, both options have their advantages and disadvantages. The advantages of using the park area is that the tree lines along Nya Allén can be saved to some extent and also that the car traffic on the street can be maintained for some time during construction. The major disadvantage is that old majestic trees of cultural and recreational significance have to be felled. The advantage of locating the corridor along the street on the other hand is that a large part of these trees can be saved. The major disadvantage is that the four tree lines along Nya Allén most probably have to be felled. Another disadvantage of this alternative is that it is harder to achieve a good horizontal alignment of the tracks compared to the chosen route. Which of these alternatives that is the most appropriate should be studied in further investigations.

One of the limiting factors in this thesis was the lack of geotechnical data that mainly affected the design of the rock tunnel part in Linnéstaden. Another part of the track design that is uncertain is the north connection to the existing light rail, viewed in drawing 1 in Appendix VI. As mentioned in Chapter 5.4.4 the designed corridor may be 1.5-2 meters wider during construction, which would prevent the proposed design in this part.

Chapter 6.5 and 6.6 dealt with the capacity of Allélänken and the potential unburdening of Brunnsparken. These chapter required several assumptions of the future situation, which of course leads to an uncertainty of the results. The same can be said for the cost estimate in Chapter 6.1, where the lack of data leads to a large uncertainty of the cost. Provisional arrangements as e.g. traffic rerouting may as well lead to an increased cost.

The article of Allélänken in Göteborgs-Posten June 4<sup>th</sup> generated a large number of comments from the public in different forums as well as from politicians in the following article June 5<sup>th</sup>. The criticism has overall been positive and it became obvious that many of the inhabitants of Gothenburg were discontented with the current state of the public transportations in Gothenburg. Allélänken was by many considered to result in many benefits in relation to the relatively limited cost. Negative criticism has mainly been aimed at the environmental impacts along Nya Allén and also that the proposal goes against the tradition of Gothenburg. The majority of the comments were however positive which indicates that this is a proposal worth investigating further.

## 8 Conclusions

This thesis has presented a proposal of a tramway tunnel that has the potential of to a large part solving the capacity problems in the central parts of Gothenburg's tram network. It has been shown that the proposed route between Polhemsplatsen and Linnéplatsen is possible to construct in the existing city structure of Gothenburg. It has also been shown that the route and the stations locations correspond well to the future plans in the public transportation program for Gothenburg. The route also enables extension possibilities according to the future plans of the large tram beltway structure Storkringen, with extensions to Masthugget, Lindholmen and Korsvägen.

The parts along the route that have been identified as structurally challenging are mainly Polhemsplatsen and the area along Linnégatan. The planned flyover Bangårdsviadukten will limit the space available in the area and the stretch along Linnégatan will require that vibrations are kept to a minimum in order to prevent damages to the adjacent buildings. The major environmental impact will be along Nya Allén where trees of cultural and recreational significance have to be felled. The cost of Allélänken is estimated to  $3,5 \pm 1$  billion SEK in the price level of 2012.

The purpose and intended effects of Allélänken was in the beginning of Chapter 5 summed up in five goals. These five goals are evaluated below.

*An unburdening of Brunnsparken achieved by redistribution of tram traffic.* The redistribution of tram traffic to Allélänken can be made in various ways. This thesis evaluates two scenarios where tram lines were relocated to Allélänken. The scenario where tram lines 1 and 7 operated in the tunnel by 2030, the capacity situation in Brunnsparken was similar to today with low to medium risks of overloading stops. The scenario where tram lines 1, 7, 9 and 11 operated in the tunnel by 2030 the capacity situation in Brunnsparken was proven to be more beneficial than today, with low risks of overloading at every stop.

*Significantly reduced travel time through central Gothenburg.* The travel time between Polhemsplatsen and Linnéplatsen is planned to be reduced with 10 minutes, from today's 16 to 6 minutes.

*Achieve a high capacity by designing long station platforms.* The capacity of Allélänken is very much dependent on the headway used and the length of the tram sets. The use of 60 meters tram sets with a headway of 100 seconds showed that the tunnel could handle about 44 percent of the total tram traffic through central Gothenburg by 2030. The most beneficial scenario for Brunnsparken, where 40 percent of the tram traffic was relocated to Allélänken, can thus be implemented.

*Decreased the vulnerability of the central tram network.* With an alternative route through central Gothenburg, the vulnerability of the network decreases. The same effects can be expected as a result of the tram projects Spårväg Skeppsbron and Operalänken.

*Enable strategic future extension possibilities.* As mentioned, Allélänken provides good extension possibilities according to the future plans in the public transportation program for Gothenburg.

It is of great importance that the politicians and stakeholders in Gothenburg see the potential of the proposal. The land along the route of Allélänken has to be reserved in order to not rule out the proposal by developing the land. It is also important that this is done as soon as possible for several reasons. The main reason is that the capacity situation in the central parts of the city is poor already today and is expected to get increasingly worse. Another reason is to plan for Allélänken when designing Västlänken's Station Haga, where a reinforcement of the roof of Västlänken should be done in a similar way as it was with Götatunneln.

This Master's thesis has provided a background to the current state of the Gothenburg tram network, presented the proposal of Allélänken and also analyzed the potential effects. The thesis should be considered as an initial study of the proposal and several more areas should further be investigated. Examples of studies are the possibility of extending current platforms towards Angered/Bergsjön and Tynnered, the geotechnical prerequisites along the route and in which way the existing traffic can be rerouted during construction.

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# Appendices

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## Appendix I – Overview map

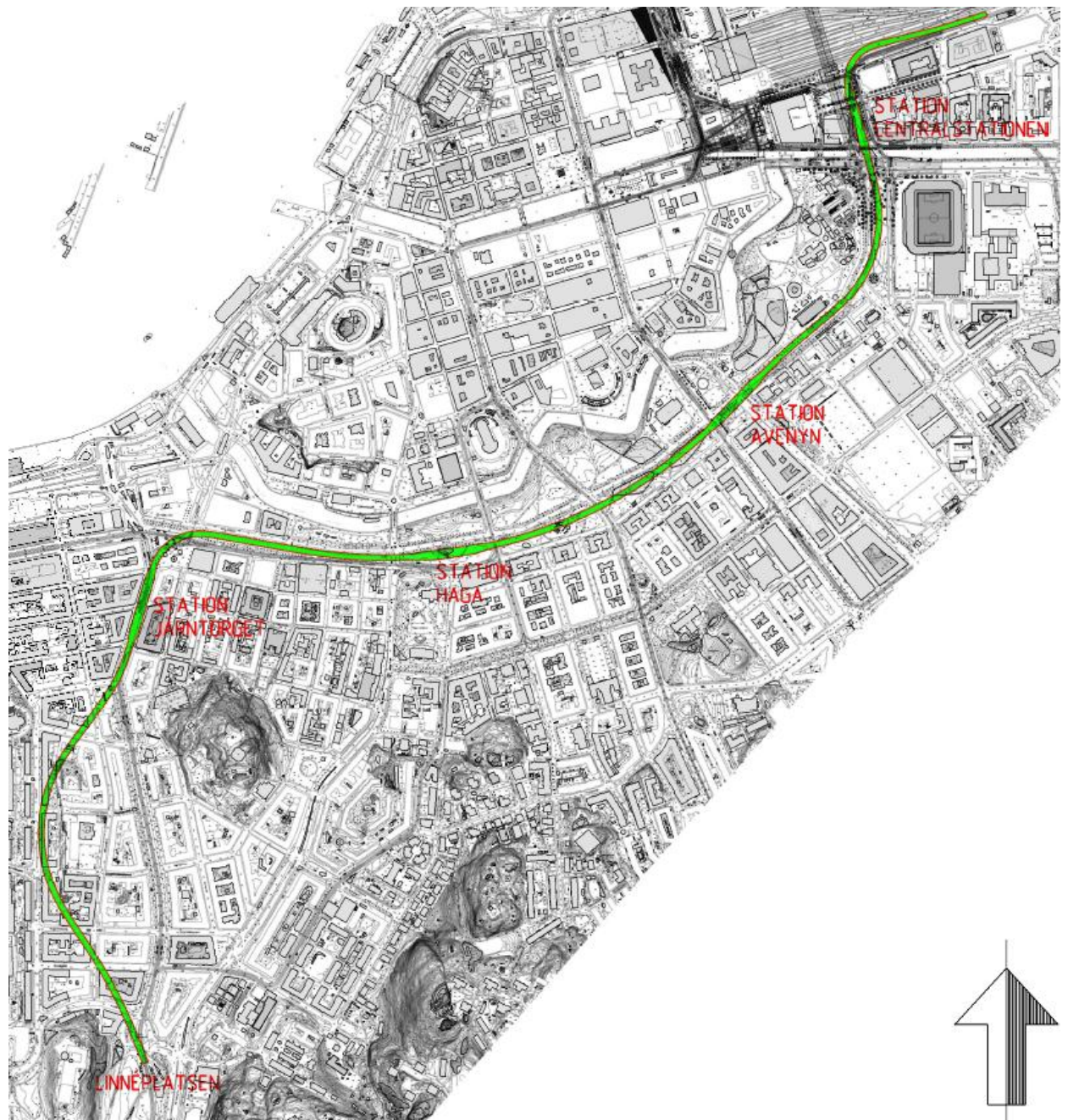


Figure A.I-1 Overview map of the corridor of Allélänken and its stations.





## Appendix II – Station locations

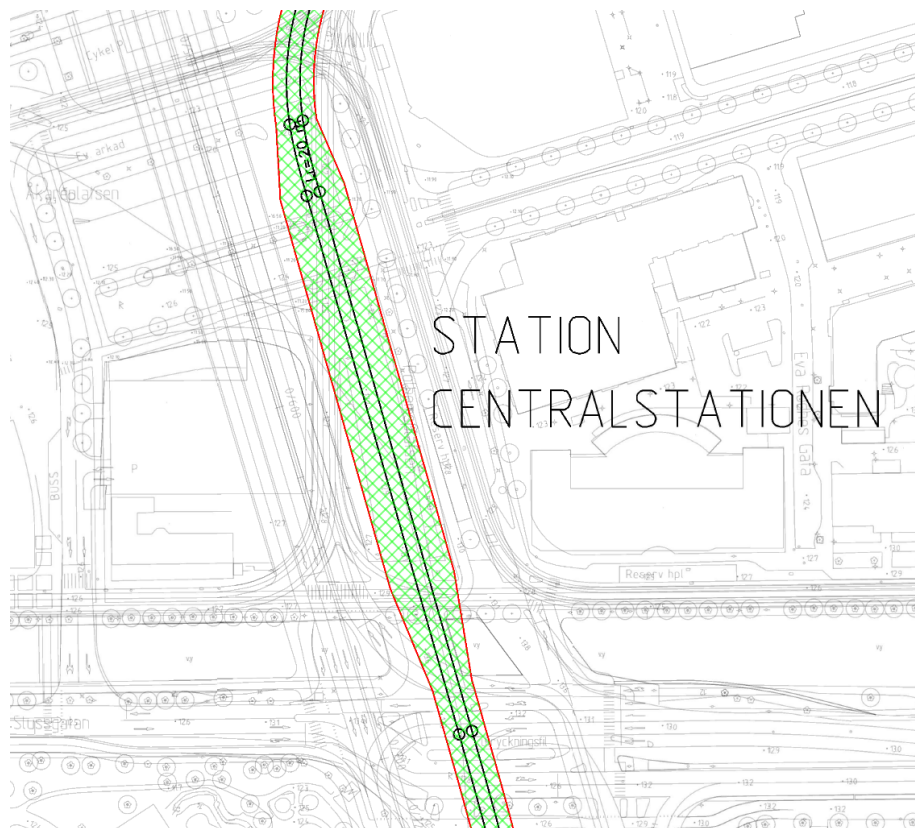


Figure A.II-1 Station Centralstationen

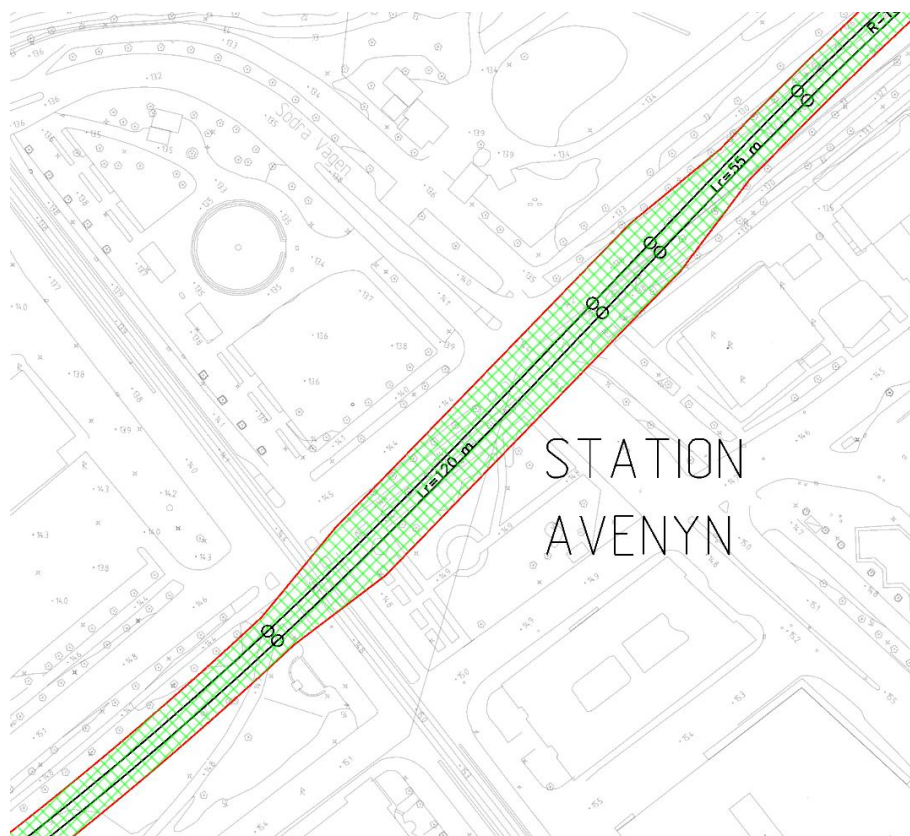


Figure A.II-2 Station Avenyn

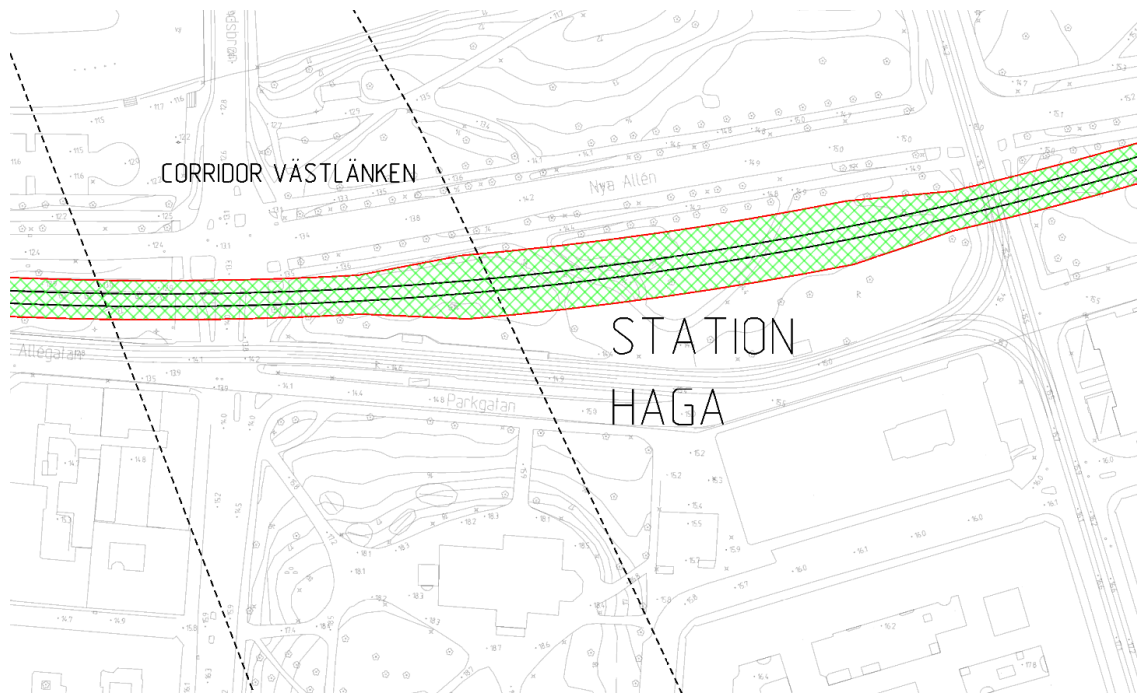


Figure A.II-3 Station Haga

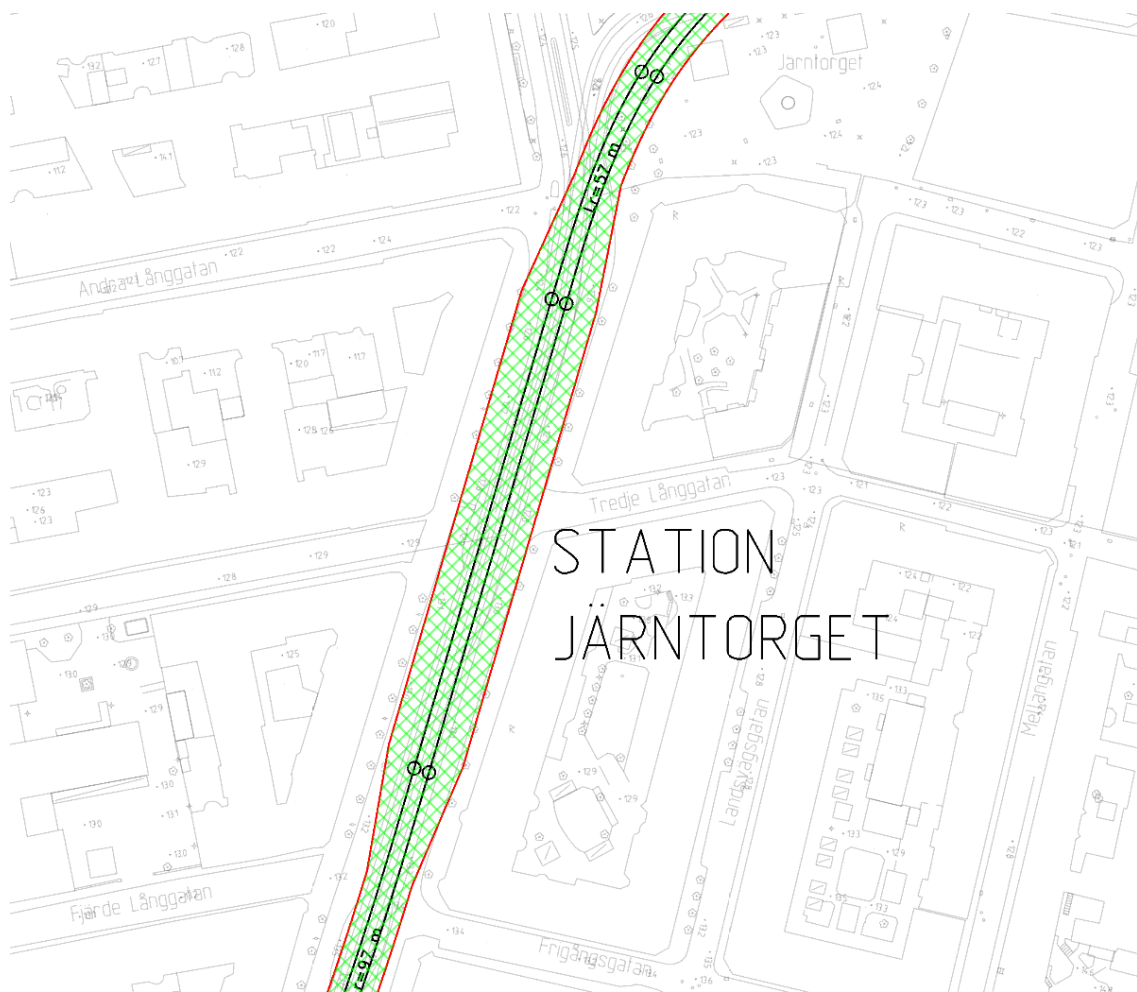


Figure A.II-4 Station Järntorget

## Appendix III – Horizontal alignment and cant

This appendix views a report generated by the software Bentley Rail Track. The tracks included in the tramway design are viewed with their associated data.

Abbreviations:	C	RL	ÖK	Ha
<u>Swedish</u>	Kurva	Rak linje	Övergångskurva	Rälsförhöjning i mm
<u>English</u>	Curve	Straight line	Spiral	Applied cant in mm

### Anslutning Nedspår

Track: *Anslutning Nedspår*

Cant: *Rälsförhöjning Anslutning Nedspår*

	<u>Section</u>							
	<u>Type</u>	<u>Length</u>	<u>Radius</u>	<u>Parameter</u>	<u>X</u>	<u>Y</u>	<u>Bearing</u>	<u>Ha</u>
C	-0+879.016	599.28			6399076	149120	4.28	
		39.8936			6399060	149083	4.35	
RL	-0+839.123				6399060	149083	4.34	
		6.8146			6399058	149077	4.34	
RL	-0+832.308				6399058	149077	4.35	
		44.0613			6399042	149036	4.35	
C	-0+788.247	500.00			6399042	149036	4.35	
		26.0820			6399034	149011	4.40	
RL	-0+762.165				6399034	149011	4.40	
		171.6785			6398981	148848	4.40	
ÖK	-0+590.486	-0.00	77.4597		6398981	148848	4.40	
		20.0000	-300.00		6398974	148829	4.37	
C	-0+570.486	-300.00			6398974	148829	4.37	
		20.4142			6398967	148810	4.30	
ÖK	-0+550.072	-300.00	77.4597		6398967	148810	4.30	
		20.0000	-0.00		6398958	148792	4.26	

RL	-0+530.072			6398958	148792	4.26
	28.6846			6398946	148766	4.26
ÖK	-0+501.387	0.00	109.5445	6398946	148766	4.26
	30.0000	400.00		6398933	148739	4.30
C	-0+471.387	400.00		6398933	148739	4.30
	18.3017			6398926	148722	4.35
ÖK	-0+453.086	400.00	109.5445	6398926	148722	4.35
	30.0000	0.00		6398916	148694	4.39
RL	-0+423.086			6398916	148694	4.39
	4.0432			6398915	148690	4.39
	-0+419.042					

## Anslutning Uppspår

Track: *Anslutning Uppspår*

Cant: *Rälsförhöjning Anslutning Uppspår*

	<u>Section</u>					
<u>Type</u>	<u>Length</u>	<u>Radius</u>	<u>Parameter</u>	<u>X</u>	<u>Y</u>	<u>Bearing</u> <u>Ha</u>
C	0+352.426	435.99		6399032	149032	4.31
	39.8826			6399018	148995	4.40
C	0+392.308	1600.00		6399018	148995	4.40
	6.8081			6399016	148988	4.40
RL	0+399.116			6399016	148988	4.41
	64.2962			6398996	148927	4.41
C	0+463.413	-1000.00		6398996	148927	4.71
	6.8532			6398996	148927	4.71
RL	0+470.266			6398996	148927	4.40
	6.8537			6398994	148920	4.40
	0+477.119					

## Bef Nedspår

Track: *Bef Nedspår*

Cant: *Rälsförhöjning Bef Nedspår*

	<u>Section</u>						
<u>Type</u>	<u>Length</u>	<u>Radius</u>	<u>Parameter</u>	<u>X</u>	<u>Y</u>	<u>Bearing</u>	<u>Ha</u>
RL	0+000.000			6398910	148691	1.24	
	156.8386			6398961	148840	1.24	
C	0+156.839	-8000.00		6398961	148840	1.24	
	31.3799			6398971	148869	1.24	
RL	0+188.219			6398971	148869	1.24	
	58.0850			6398990	148924	1.24	
ÖK	0+246.304	-0.00	178.8854	6398990	148924	1.24	
	20.0000	-1600.00		6398997	148943	1.23	
C	0+266.304	-1600.00		6398997	148943	1.23	
	212.6198			6399081	149138	1.10	
	0+478.923						

## Nedspår

Track: *Nedspår*

Cant: *Rälsförhöjning Nedspår*

	<u>Section</u>						
<u>Type</u>	<u>Length</u>	<u>Radius</u>	<u>Parameter</u>	<u>X</u>	<u>Y</u>	<u>Bearing</u>	<u>Ha</u>
RL	-0+888.690			6399080	149129	4.28	
	87.3831			6399043	149050	4.28	
C	-0+801.307	500.00		6399043	149050	4.28	
	59.9866			6399022	148994	4.40	
RL	-0+741.320			6399022	148994	4.40	0.00
	122.7837			6398984	148877	4.40	0.00



ÖK	-0+618.537	0.00	173.2051	6398984	148877	4.40	0.00
	30.0000	1000.00		6398975	148848	4.42	70.00
C	-0+588.537	1000.00		6398975	148848	4.42	70.00
	43.1503			6398963	148807	4.46	70.00
ÖK	-0+545.386	1000.00	173.2051	6398963	148807	4.46	70.00
	30.0000	0.00		6398956	148778	4.47	0.00
RL	-0+515.386			6398956	148778	4.47	0.00
	67.0133			6398940	148712	4.47	0.00
ÖK	-0+448.373	-0.00	62.0399	6398940	148712	4.47	0.00
	49.0000	-78.55		6398924	148667	4.16	50.00
C	-0+399.373	-78.55		6398924	148667	4.16	50.00
	91.7923			6398845	148630	2.99	50.00
ÖK	-0+307.581	-78.55	39.6358	6398845	148630	2.99	50.00
	20.0000	-0.00		6398826	148635	2.87	0.00
RL	-0+287.581			6398826	148635	2.87	0.00
	152.5381			6398679	148676	2.87	0.00
ÖK	-0+135.043	0.00	149.1643	6398679	148676	2.87	0.00
	89.0000	250.00		6398592	148695	3.04	100.00
C	-0+046.043	250.00		6398592	148695	3.04	100.00
	199.5623			6398407	148637	3.84	100.00
ÖK	0+153.520	250.00	149.1643	6398407	148637	3.84	100.00
	89.0000	0.00		6398346	148573	4.02	0.00
RL	0+242.520			6398346	148573	4.02	0.00
	20.3698			6398333	148557	4.02	0.00
ÖK	0+262.889	-0.00	234.9367	6398333	148557	4.02	0.00
	55.0000	-1003.55		6398297	148515	3.99	100.00
C	0+317.889	-1003.55		6398297	148515	3.99	100.00
	63.4047			6398254	148468	3.93	100.00

ÖK	0+381.294	-1003.55	234.9367	6398254	148468	3.93	100.00
	55.0000	-0.00		6398215	148430	3.90	0.00
RL	0+436.294			6398215	148430	3.90	0.00
	21.7229			6398199	148415	3.90	0.00
ÖK	0+458.017	0.00	346.4102	6398199	148415	3.90	0.00
	120.0000	1000.00		6398114	148331	3.96	40.00
C	0+578.017	1000.00		6398114	148331	3.96	40.00
	864.9816			6397852	147534	4.83	40.00
ÖK	1+442.999	1000.00	346.4102	6397852	147534	4.83	40.00
	120.0000	0.00		6397870	147416	4.89	0.00
RL	1+562.999			6397870	147416	4.89	0.00
	118.1586			6397891	147300	4.89	0.00
ÖK	1+681.157	-0.00	76.8268	6397891	147300	4.89	0.00
	57.0000	-103.55		6397896	147243	4.61	100.00
C	1+738.157	-103.55		6397896	147243	4.61	100.00
	94.2647			6397848	147166	3.70	100.00
ÖK	1+832.422	-103.55	76.8268	6397848	147166	3.70	100.00
	57.0000	-0.00		6397795	147145	3.43	0.00
RL	1+889.422			6397795	147145	3.43	0.00
	113.5864			6397686	147113	3.43	0.00
ÖK	2+003.008	0.00	170.5872	6397686	147113	3.43	0.00
	97.0000	300.00		6397594	147081	3.59	100.00
C	2+100.008	300.00		6397594	147081	3.59	100.00
	10.7605			6397585	147076	3.62	100.00
ÖK	2+110.769	300.00	170.5872	6397585	147076	3.62	100.00
	97.0000	0.00		6397504	147022	3.79	0.00
RL	2+207.769			6397504	147022	3.79	0.00
	28.9215			6397481	147005	3.79	0.00

ÖK	2+236.690	-0.00	171.8587	6397481	147005	3.79	0.00
	97.3000	-303.55		6397400	146950	3.63	100.00
C	2+333.990	-303.55		6397400	146950	3.63	100.00
	276.9210			6397133	146943	2.71	100.00
ÖK	2+610.911	-303.55	171.8587	6397133	146943	2.71	100.00
	97.3000	-0.00		6397049	146993	2.55	0.00
RL	2+708.211			6397049	146993	2.55	0.00
	22.9655			6397030	147005	2.55	0.00
ÖK	2+731.177	0.00	200.0000	6397030	147005	2.55	0.00
	40.0000	1000.00		6396997	147027	2.57	100.00
C	2+771.177	1000.00		6396997	147027	2.57	100.00
	163.4655			6396853	147104	2.74	100.00
ÖK	2+934.642	1000.00	200.0000	6396853	147104	2.74	100.00
	40.0000	0.00		6396816	147119	2.76	0.00
RL	2+974.642			6396816	147119	2.76	0.00
	48.2839			6396771	147137	2.76	0.00
	3+022.926						

## Uppspår

Track: *Uppspår*

Cant: *Rälsförhöjning Uppspår*

	<u>Section</u>						
<u>Type</u>	<u>Length</u>	<u>Radius</u>	<u>Parameter</u>	<u>X</u>	<u>Y</u>	<u>Bearing</u>	<u>Ha</u>
RL	-0+664.239			6398994	148920	4.40	0.00
	43.9922			6398981	148879	4.40	0.00
ÖK	-0+620.247	0.00	173.5122	6398981	148879	4.40	0.00
	30.0000	1003.55		6398972	148850	4.42	70.00
C	-0+590.247	1003.55		6398972	148850	4.42	70.00

	44.4037			6398960	148807	4.46	70.00
ÖK	-0+545.843	1003.55	173.5122	6398960	148807	4.46	70.00
	30.0000	0.00		6398953	148778	4.47	0.00
RL	-0+515.843			6398953	148778	4.47	0.00
	66.4831			6398937	148714	4.47	0.00
ÖK	-0+449.360	-0.00	60.6218	6398937	148714	4.47	0.00
	49.0000	-75.00		6398920	148668	4.15	50.00
C	-0+400.360	-75.00		6398920	148668	4.15	50.00
	86.1277			6398846	148634	3.00	50.00
ÖK	-0+314.232	-75.00	38.7298	6398846	148634	3.00	50.00
	20.0000	-0.00		6398827	148638	2.87	0.00
RL	-0+294.232			6398827	148638	2.87	0.00
	152.7509			6398680	148680	2.87	0.00
ÖK	-0+141.481	0.00	150.2197	6398680	148680	2.87	0.00
	89.0000	253.55		6398593	148699	3.04	100.00
C	-0+052.481	253.55		6398593	148699	3.04	100.00
	203.5523			6398404	148640	3.84	100.00
ÖK	0+151.071	253.55	150.2197	6398404	148640	3.84	100.00
	89.0000	0.00		6398343	148575	4.02	0.00
RL	0+240.071			6398343	148575	4.02	0.00
	20.4575			6398330	148559	4.02	0.00
ÖK	0+260.529	-0.00	234.5208	6398330	148559	4.02	0.00
	55.0000	-1000.00		6398295	148517	3.99	100.00
C	0+315.529	-1000.00		6398295	148517	3.99	100.00
	62.9859			6398252	148471	3.93	100.00
ÖK	0+378.515	-1000.00	234.5208	6398252	148471	3.93	100.00
	55.0000	-0.00		6398212	148433	3.90	0.00
RL	0+433.515			6398212	148433	3.90	0.00

	21.7239			6398196	148418	3.90	0.00
ÖK	0+455.238	0.00	347.0245	6398196	148418	3.90	0.00
	120.0000	1003.55		6398111	148333	3.96	40.00
C	0+575.238	1003.55		6398111	148333	3.96	40.00
	868.4783			6397848	147534	4.83	40.00
ÖK	1+443.717	1003.55	347.0245	6397848	147534	4.83	40.00
	120.0000	0.00		6397867	147415	4.89	0.00
RL	1+563.717			6397867	147415	4.89	0.00
	118.1237			6397887	147299	4.89	0.00
ÖK	1+681.840	-0.00	75.4983	6397887	147299	4.89	0.00
	57.0000	-100.00		6397892	147242	4.60	100.00
C	1+738.840	-100.00		6397892	147242	4.60	100.00
	89.0789			6397846	147169	3.71	100.00
ÖK	1+827.919	-100.00	75.4983	6397846	147169	3.71	100.00
	57.0000	-0.00		6397794	147148	3.43	0.00
RL	1+884.919			6397794	147148	3.43	0.00
	113.5522			6397685	147116	3.43	0.00
ÖK	1+998.472	0.00	171.5936	6397685	147116	3.43	0.00
	97.0000	303.55		6397593	147084	3.59	100.00
C	2+095.472	303.55		6397593	147084	3.59	100.00
	12.0357			6397583	147079	3.63	100.00
ÖK	2+107.507	303.55	171.5936	6397583	147079	3.63	100.00
	97.0000	0.00		6397502	147025	3.79	0.00
RL	2+204.507			6397502	147025	3.79	0.00
	28.9134			6397479	147007	3.79	0.00
ÖK	2+233.421	-0.00	170.8508	6397479	147007	3.79	0.00
	97.3000	-300.00		6397398	146953	3.62	100.00
C	2+330.721	-300.00		6397398	146953	3.62	100.00

	272.5445			6397135	146946	2.71	100.00
ÖK	2+603.265	-300.00	170.8508	6397135	146946	2.71	100.00
	97.3000	-0.00		6397051	146996	2.55	0.00
RL	2+700.565			6397051	146996	2.55	0.00
	22.9556			6397032	147008	2.55	0.00
ÖK	2+723.521	0.00	200.3547	6397032	147008	2.55	0.00
	40.0000	1003.55		6396999	147030	2.57	100.00
C	2+763.521	1003.55		6396999	147030	2.57	100.00
	164.1878			6396854	147107	2.74	100.00
ÖK	2+927.708	1003.55	200.3547	6396854	147107	2.74	100.00
	40.0000	0.00		6396817	147122	2.76	0.00
RL	2+967.708			6396817	147122	2.76	0.00
	48.2839			6396772	147141	2.76	0.00
	3+015.992						





## Appendix IV – Tunnel sections

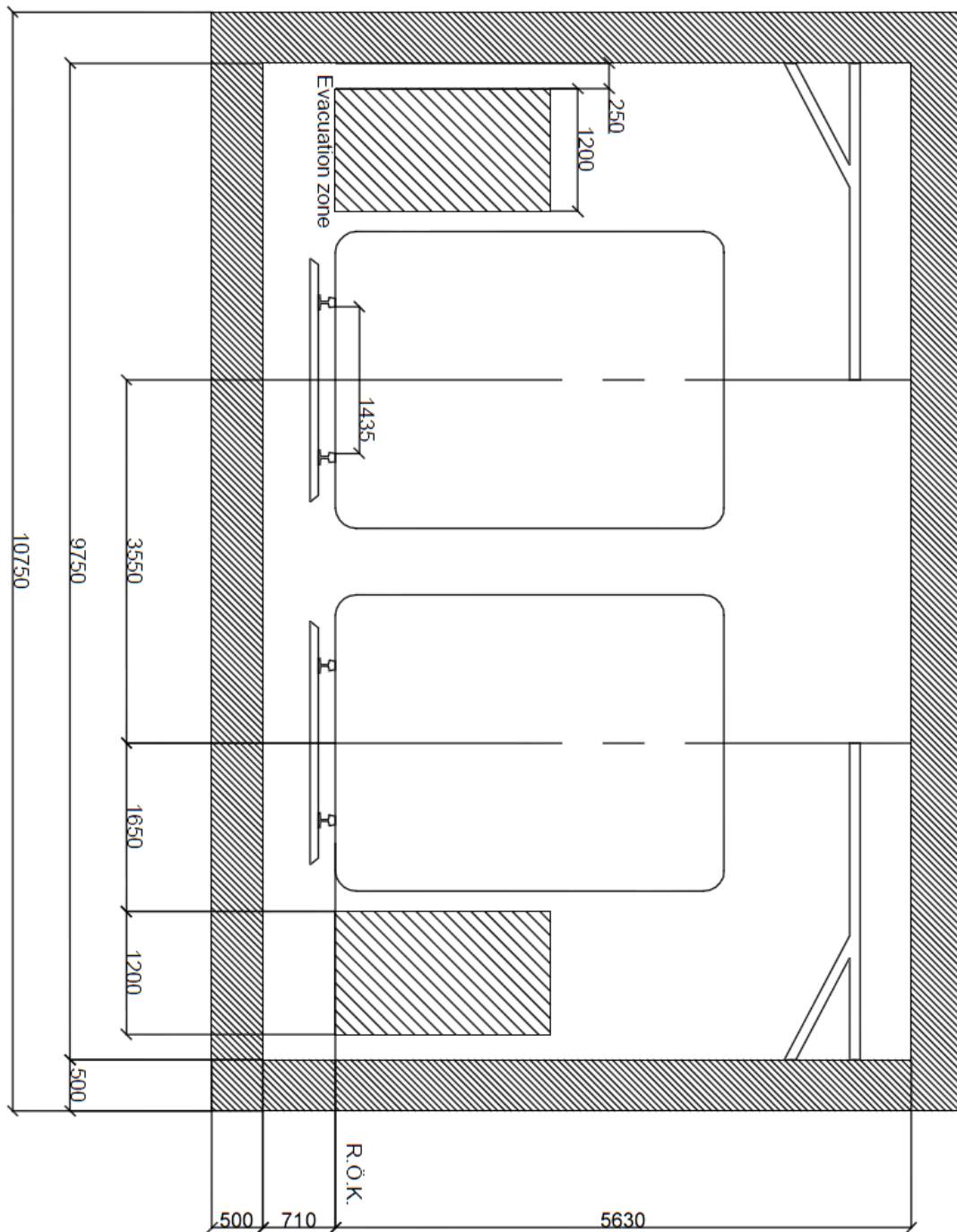


Figure A.IV-1 Sketch of concrete tunnel section between stations

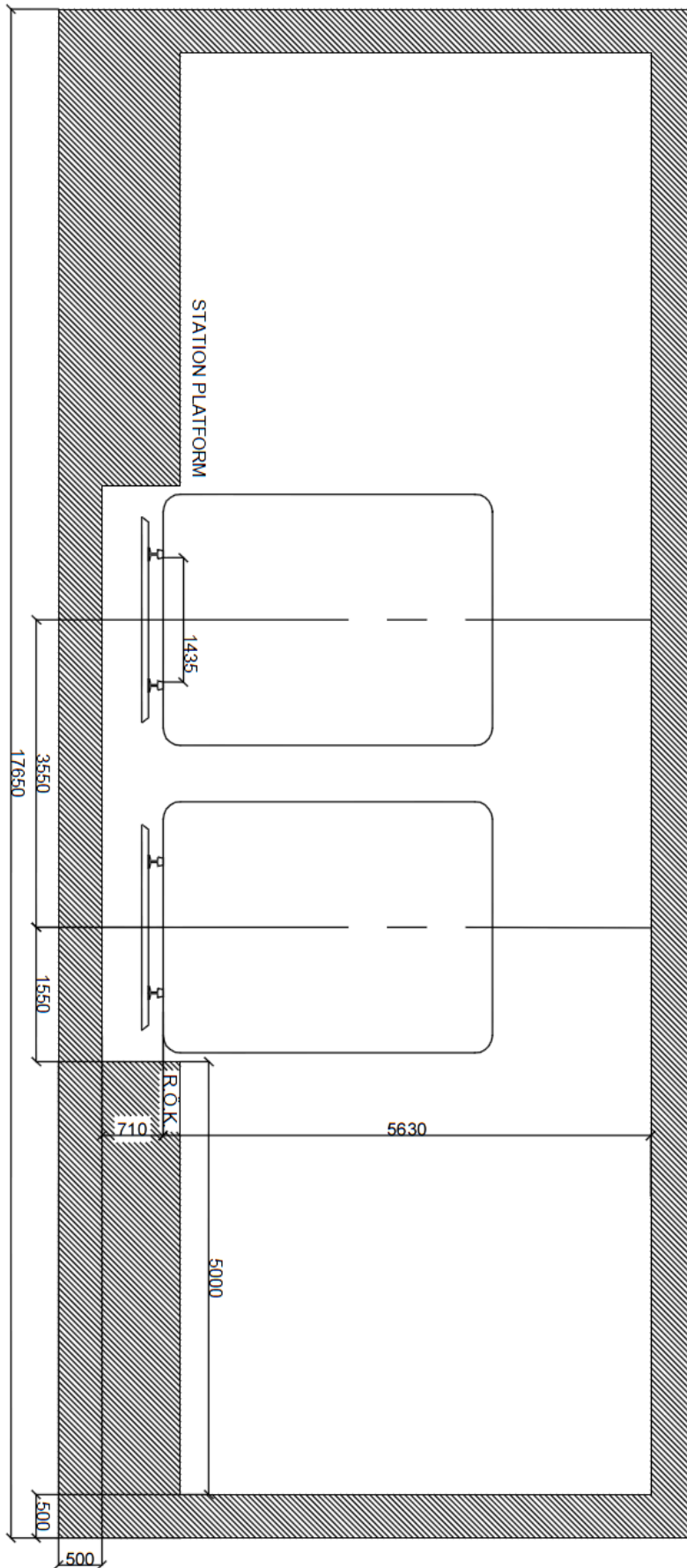
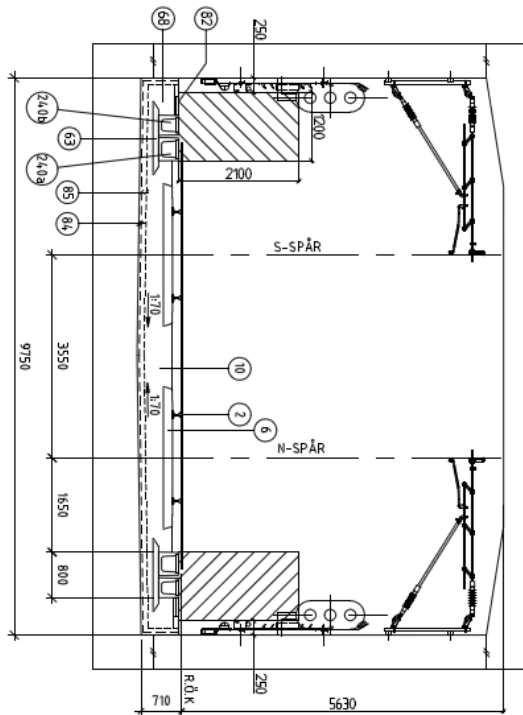


Figure A.IV-2 Sketch of concrete tunnel section at station



BETONGTUNNEL MARGRETELUND  
 RAKKSPÅR  
 SKALA 1:50

NR	BENÄMNING	MATERIAL	AMKOD	ANMÄRKNING
2	RÅL	TYP 50E3 (8x50)	DFB.2	HÖJD 95 mm
6	SUPERS	BETONG	DEC.11	SL1
10	SPÅRBALLAST	MAKADAM BALLAST 500mm	DCH.311	SL1
63	LEDNINGSPÅDD FÖR KABELRÄNNANNA	KROSSMATERIAL D=32 FÖR KABELL. CEL/1. FÖR KL. E= 100mm	CEC.221	
68	KRINGFYLNING FÖR KABELRÄNNANNA	KROSSMATERIAL D=32 ENL. TABELL CEL/1.	CEC.322	
82	GÅNGBENYTTA	BETONGPLATTOR 400x400x50	DGG.21	
84	Aq	BÄRLAGER AV ASFALTGRUS MED FÖRHÖJD BINDEREBELSHALT VID NYBYGGERÅLD	DCC.2121	1,40 mm
85	STOMJUISISOLERING	VARERER BETONG	DBF.9	BREDD 410 mm FÖR EST
240B	KABELRÄNNANNA		DEW.15	BREDD 350 mm FÖR 33 kV
240B	KABELRÄNNANNA		DEW.15	

Figure A.IV-3 Tunnel section of concrete tunnel Margretelund (Ramböll, 2009)



## **Appendix V – Newspaper article and comments**

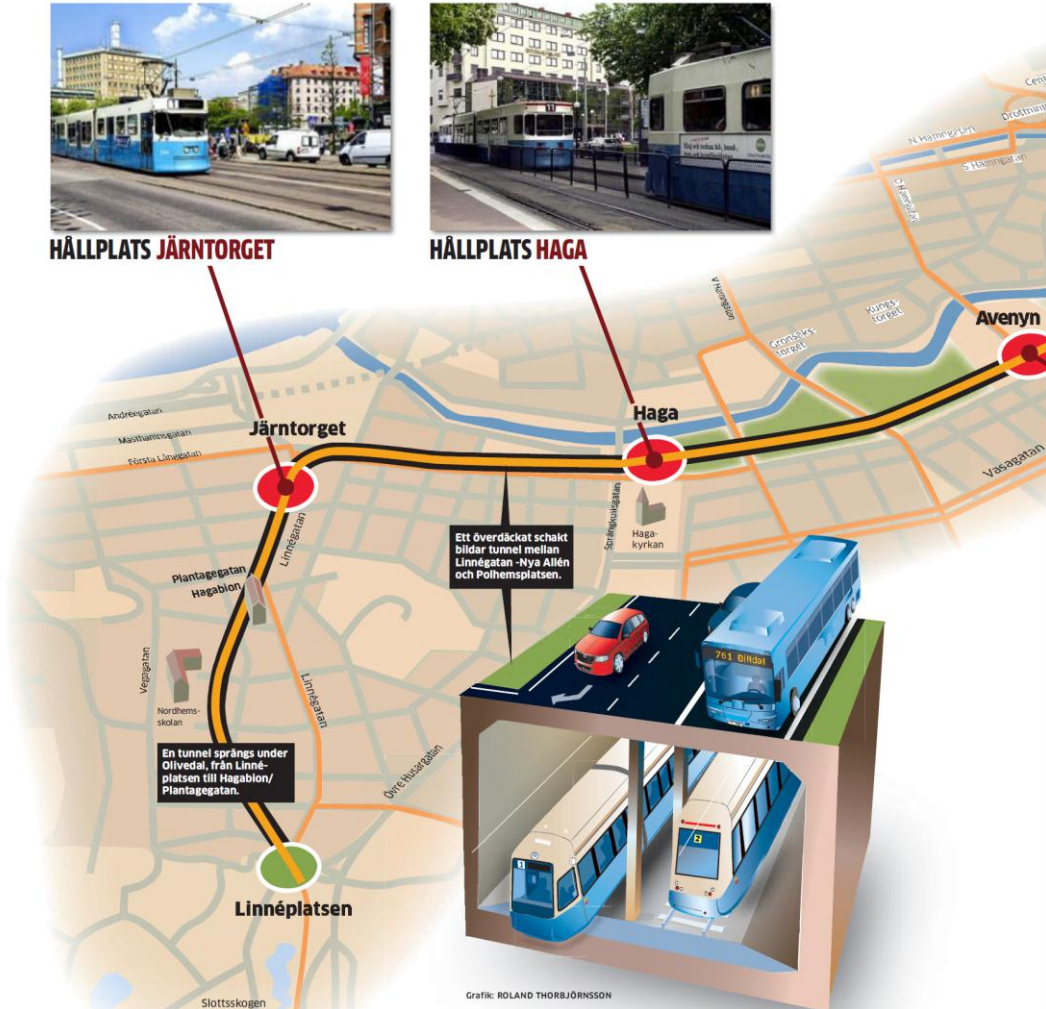
The newspaper Göteborgs-Posten published an article about Allélänken on June 4<sup>th</sup>, 2012. The newspaper also published an article the day after, on June 5<sup>th</sup>, including comments from mainly politicians in Gothenburg. These two articles are presented in this appendix.

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**MÅNDAG**

Redaktör: Cecilia Frisk 031-62 40 89 • Biträdande redaktörer: Linda Swanberg 031-62 40 39, Eskil Lundgren 031-62 42 73, Evalis Björk 031-62 46 03. E-post: nyheter@gp.se • Fax: 031-80 27 69.

**HÅLLPLATS JÄRNTORGET****HÅLLPLATS HAGA**

Grafik: ROLAND THORBJÖRNSSON

# Lösningen: tunnel

**GÖTEBORG:** Spårvagnarna stänger sig sakta genom centrala Göteborg, medelhastigheten är inte mer än tio kilometer i timman. Men det finns en effektiv lösning: spårvägstunnel under Nya allén.

Med en tunnel mellan Polhemsplassen och Linnéplatsen kan resan genom centrala Göteborg förkortas med nio minuter, från femton till sex minuter.

En tunnel under bilarna i Nya allén blir flera miljarder kronor

## Så kan vagnen köra snabbare genom stan

billigare än en tunnel under hus tvärs under stan.  
– Vi behöver inte gräva ner oss mer än sju-åtta meter, säger Martin Rudolphi och Partrik Sterky. Det blir mycket enklare och billigare än att gå ner 10-20 meter under husen.

**RUDOLPHI** är sistaårselev på Chal-

mers och gör sitt examensjobb om Allélinken under handledning av Sterky på teknikonsultföretaget Ramböll. De tror inte det finns så många andra möjligheter att snabba upp resorna och öka kapaciteten genom centrala Göteborg.

– Även om de flesta bussarna föresligger från Brunnsparken när busskörfältet förbi Drottningtorget och i Nya allén blir klara kommer det åter att vara fullt i Brunnsparken om tio år, säger Sterky.

– Det räcker inte heller med ny spårväg på Södra älvstranden, det är ändå för många vagnar, för

mycket trafik och för många bilar och fotgängare i vägen.

**DET ÄR SVÅRT** och dyrt att bygga tunnlar under Göteborg. Det beror delvis på att det är besvärligt att bygga i leran men dyra grundförstärkningar under husen driver upp kostnaden rejält.

– Om vi bygger spårvägstunneln under Nya allén och i berget mellan Hagablon och Linnéplatsen blir det åtskilliga miljarder billigare än att bygga under husen i centrala stan, säger Rudolphi.

Under asfalten eller under grön-

skan mellan Parkgatan och Nya allén kan tunneln läggas strax under ytan utan konflikt med befintlig bebyggelse. Samtidigt blir spårvägstunneln ett bra komplement till Västälken med goda bytesmöjligheter vid Haga-kyrkan.

Ett viktigt skäl för en tunnel är att man kan köra långa vagnar.

– Vi behöver vagnar som är minst 60 meter om vi skall kunna transportera tillräckligt många göteborgare genom stan om 20-30 år, säger Sterky. Men det är nästan omöjligt att förlänga hållplatserna i centrala

GP:s tipstelefon: 031-17 20 10  
Publicerade tips belönas.



## 3 FÖRDELAR MED ALLÉ-TUNNELN

- Nio minuter kortare resa genom centrum
- Flera miljarder billigare än tunnel under husen
- Möjligt att köra 100 meter långa spårvagnar



HÅLLPLATS POLHEMSPLATSEN



HÅLLPLATS AVENYN

### Allé-länken kan kompletteras

- Spårvägstunneln mellan Polhemsplatsen och Linnéplatsen kan kompletteras med en tunnel från Järntorget mot Stigbergstorget som kan ge betydligt kortare resor till Majorna och Saltholmen.
- Med en tunnel från Stigbergstorget under allen till Eriksberg på Hisingen kan spårvagnsresorna mellan Järntorget och Norra Älvstranden gå på några minuter.
- Med spår på Bangårdsviadukten över järnvägen vid Göteborg C skapas en snabb förbindelse till nya Götaälvbron och Hisingen.

### Kostnad: 3,4 miljarder

- Tunnelspecialisterna på Ramböll har uppskattat kostnaden för en 3,4 kilometer lång tunnel Polhemsplatsen-Linnéplatsen via Järntorget till 3,5 miljarder kronor plus/minus en miljard kronor.
- I kostnaden ingår fyra underjordiska hållplatser: Polhemsplatsen, Avenyn, Hagakyrkan och Järntorget.

# under allén



**Chatta** med personerna bakom förslaget. 11.00 i dag på gp.se svarar Martin Rudolphi och Patrik Sterky på dina frågor.  
[www.gp.se](http://www.gp.se)

.SE

stan för vagnar som är mer än 35 meter.

De yttre delarna av spårvägsnätet är byggt för längre vagnar utan plankorsningar och med egen banvall.

Hållplatserna på spårvägarna till Angered och till Bergsjön är redan tillräckligt långa eller förberedda för att förlängas för 60-metersvagnar och hållplatserna på Hisingen och ut till Tynnered kan relativt enkelt förlängas.

I ETT TIOOTAL tyska städer kör man 60-75 meter långa spårvagnar i tunnel under stadskärnorna.

Utanför centrum går vagnarna på gator och egna banvallar.

– Tunnelstationerna borde byggas för 100 meter långa vagnar. Då blir det möjligt att konvertera spårvägstunneln till tunnelbana i framtiden på samma sätt som man förvandlat delar av spårvägarna i Oslo till tunnelbanor.

Med Allé-länken kan en spårvägslinje mellan Angered och Tynnered få samma medelhastighet som den röda linjen på tunnelbanan i Stockholm, 35 km/h.

ULF NYSTRÖM

031-62 41 29 ulf.nystrom@gp.se

## I KORTHET

### Pistol beslagtagn på rejvfest

**GÖTEBORG:** Tre personer greps i går eftermiddag i samband med ett rejv vid Rya skog, sedan ett skjutvapen hittats.

– Där hade varit ett rejvfest hela natten och det var fortfarande mycket folk kvar på platsen, 50-60 personer, säger Thomas Fuxborg på polisen.

Polisen förde med sig tre personer, samtliga misstänkta för ringa narkotikabrott. Man beslagtog även en pistol. Två av de tre gripna misstänks alltså också för brott mot vapenlagen. Männen är i 35-årsåldern.



.SE

### Dubbelmord upp i rätten

I dag startar rättegången mot männen som är misstänkta för mordet i Långared. GP är på plats i tingsrätten.  
[www.gp.se](http://www.gp.se)

### Handlare hoppas på EM och OS

**STOCKHOLM:** I fjol föll försäljningen rejält, och under de fyra första månaderna 2012 har den ökat med endast 0,5 procent. Nu hoppas den pressade hemelektronikkhandeln att fotbolls-EM och sommar-OS ska ge ett uppsving.

– Det betyder nog ganska mycket, tror jag, säger Klas Elm, vd för branschföreningen Elektronikbranschen, om de stundande evenemangen.

Det långvariga priskriget på marknaden fick i fjol en av de största aktörerna, Onoff, att gå omkull. (TT)

.SE

### Mest läst i går

Efter en intensiv jakt i polisbil lyckades Patrick Fabrizius hitta mannen som stulit hans i-phone en halvtimme tidigare.



**MARGOT WALLSTRÖM:** Finns det något sätt som jag kan bidra på så gör jag gärna det.

Förre EU-kommissionären, tidigare ofta tipad som partiledare, öppnar för nya uppdrag inom Socialdemokraterna när hon intervjuas i SVTs Agenda. (TT)

### Skottlossning vid rån på båt

**STOCKHOLM:** Ett väpnat rån genomfördes vid 19-tiden i går mot ett växlingskontor ombord på en av Danmarksfärjorna då den låg i Helsingborgs hamn.

Flera skott avlossades av två gärningsmän som var beväpnade med automatvapen och pistol men ingen person har skadades fysiskt. De båda gärningsmännen flydde på motorcyklar.

Enligt Peter Martin, länsavskrivande polisbefäl i Skåne, pågår ett mycket stort efterspanningsarbete i Helsingborg. Rånarna fick med sig en ökad summa kontanter. (TT)

### 83-åring konfirmerade sig



**STRÖMSUND:** I går blev det äntligen 83-åriga Astrid Johansson tur att konfirmera sig.

– Jag trodde aldrig att jag skulle få uppleva det här, säger hon.

Det var i höstas som församlingen erbjöd äldre, som av någon anledning inte konfirmerat sig när de var unga, att börja läsa.

– Jag trodde att för skulle ha på men jag har varit ensam, säger Astrid Johansson.

Hon konfirmerades i Hotings kyrka i Jämtland. (TT)

### SNF emot slutförvaring

**STOCKHOLM:** Kärnkraftsindustrins ansökan om slutförvaring av använt kärnbränsle är full av brister, anser Naturskyddsföreningen (SNF).

Tillsammans med Miljöorganisationernas kärnavfallsgranskning (MKG) har de gått igenom förslaget om ett slutförvar i Forsmark och kommit fram till att underlaget brister och att det krävs mer forskning. Industrin hävdar att barriärerna ska hålla i hundratals år, men föreningarna anser att det finns risk att de går sönder redan innan tusen år. (TT)





UR GÅRDAGENS GP.

# Många tror på tunnel

**GÖTEBORG: Många gillar idén om en spårvagnstunnel under Nya Allén. Men alla tror inte att den blir verklighet.**

Den som brukar ta spårvagnen genom centrala Göteborg vet att det ofta går snabbare att knalla för egen maskin. Men i gårdagens GP presenterades en lösning som skulle kunna mer än halvera restiderna i centrum.

Chalmersstudenten Martin Rudolph och hans handledare Patrik Sterky har arbetat fram förslaget som låter spårvagnarna susa fram genom en tunnel under Nya Allén, mellan Järntorget och Polhemsplatsen. Flera av stadens ansvariga politiker och tjänstemän är positiva när de får tycka till om förslaget.

- **DET ÄR EN** väldigt intressant idé och jag tror att de hittat rätt ställe att göra det på. Just den här typen av strategiska förslag måste börja diskuteras för att vi ska kunna fortsätta att utveckla kollektivtrafiken efter 2020, säger Västtrafiks ordförande Leif Blomqvist, S.

I egenskap av regionråd med



Bild: ELISABETH ALVENBY

**TVEKSAM.** Anna Helander leker med barnen Sigrid och Vilgot i Hagaparken. Hon åker inte spårvagn särskilt ofta men tycker spontant inte att det behövs någon spårvagnstunnel mellan Järntorget och Polhemsplatsen. "Jag tycker att det är trevligare att åka om man kan se ut längs vägen", säger hon.

ansvar för infrastrukturfrågor ska Leif Blomqvist göra vad han kan för att satsningar i stil med spårvagnstunneln kommer med i nästa investeringsplan.

- Vi måste börja diskussionerna nu. Ett projekt av den här typen tar minst tio år att finansiera och genomföra, säger han.

Även Roland Rydin, M, vice ordförande i trafiknämnden gillar förslaget.

- Det skulle bli en riktig kvalitetsförbättring för kollektivtrafiken i Göteborg. Restiderna är ett av de största problemen vi har när det gäller att konkurrera med bilen. Får vi ner restiderna skulle fler åka kollektivt, säger han.

**EN LIKANDE UNDERJORDISK** spårvagnsslinga har tidigare utretts för sträckan Korsvägen-Kungssportsplatsen. Enligt Roland Rydin kom man då fram till en kostnad på 1 miljon per meter vilket skulle ge en totalnota på 1,3 miljarder.

- Jag tycker att vi successivt skulle lägga spårvägen under marken. Det är fullt tekniskt möjligt, säger Roland Rydin.

Göteborgs spårvägars plane-

ringschef Kent Lindahl tycker också att själva idén är bra. Däremot ser han inte det som särskilt troligt att den faktiskt kommer att byggas.

- Visst skulle det öka framkomligheten om man fick till detta. Men problemet är att det inte finns

## "Det skulle bli en riktig kvalitetsförbättring för kollektivtrafiken"

ROLAND RYDIN, M, vice ordförande i trafiknämnden

någon plan för hur man exempelvis skulle korsa Västlänken vid Hagakyrkan. Sedan är det kostnadskrävande att gräva en så lång sträcka i mark där det ligger avlopp, vattenrör och fjärrvärme och det skulle bli väldiga avstängningar under byggtiden, säger han.

Kommunalsrådet Jonas Ransgård, M, reserverar sig också för att det kan finnas både tekniska och ekonomiska hinder men är annars positiv till spårvagnstunneln.

- Det känns väldigt smakligt,

rent spontant. Allén är en av de få tvärgående stråk vi har, att öka framkomligheten där vore väldigt bra, säger han.

Kommunstyrelsens ordförande Anneli Hulthén, S, beskriver förslaget som en kul och intressant idé och välkomnar att man tänkt till kring kollektivtrafiken.

- Sedan vet jag inte hur det passar in i det övriga systemet. Men att vi behöver arbeta vidare på att utveckla kollektivtrafiken är helt klart. Då kan detta vara en variant, säger hon.

**BLAND DE VANLIGA** göteborgare vi pratat med finns både positiva och mer tveksamma röster. Men för Håkan Strandhag, som vi träffar på vid Hagaparken, är förslaget klockrent.

- Det är jättebra. Det är ju absurd att det ska ta lika lång tid mellan Järntorget och Brunnsparken som det gjorde för hundra år sedan när hästar drog vagnarna. De får gärna fortsätta med tunneln bort till Stigbergstorget också så att vi bygger ihop centrum med Majorna, säger han.

KAROLINA VIKINGSSON

031 62 48 44 karolina.vikingsson@gp.se

## Appendix VI – Track design

This appendix contains the track design performed in the software Bentley Microstation and Bentley Rail Track. The track design is viewed format A3 in scale 1:1000. The overview map in Figure A.VI-1 shows the order in which the pages are presented.

The tracks are presented with filled lines and the corridor, i.e. the width of the tunnel construction, is presented with dotted lines.

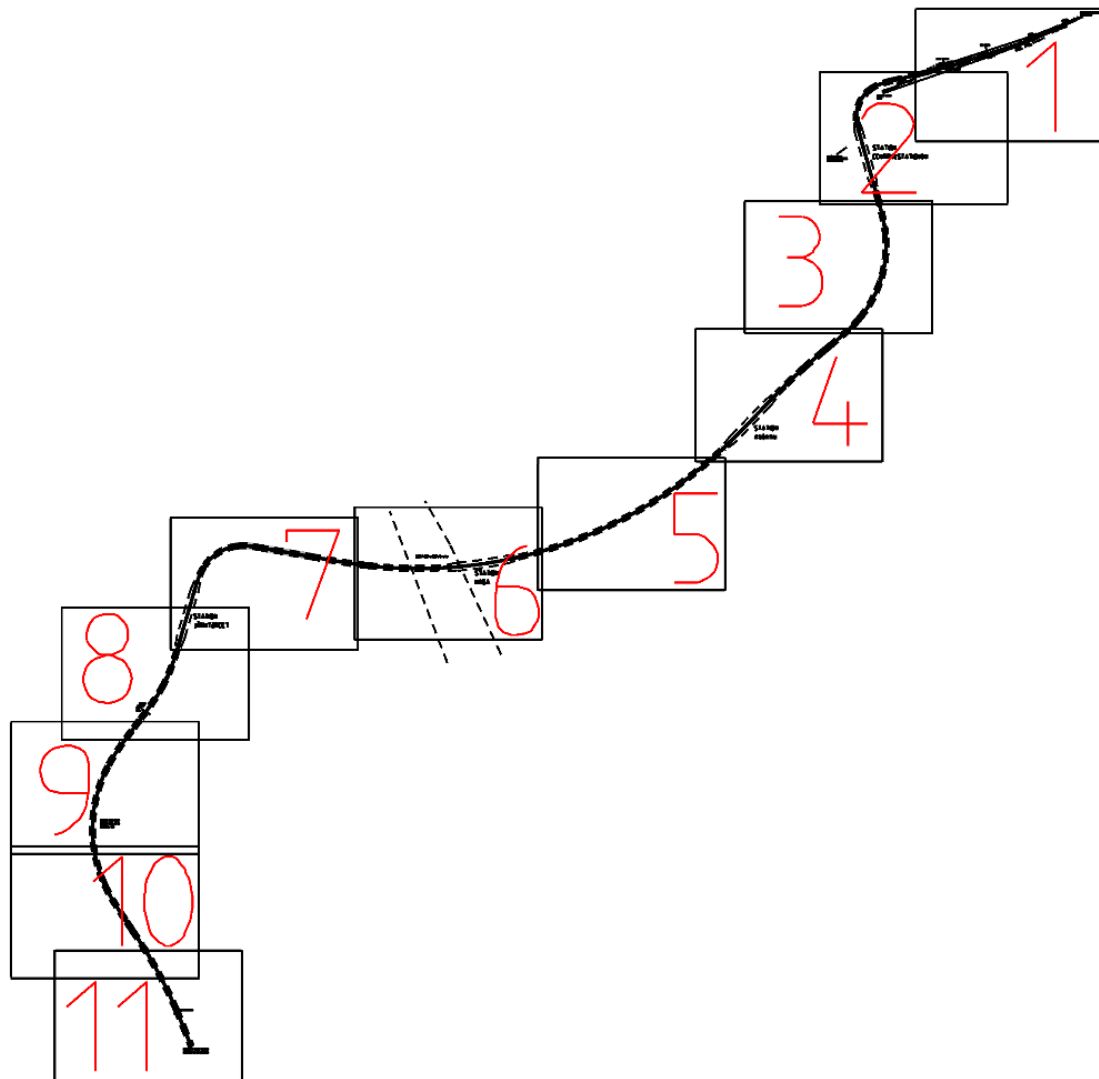
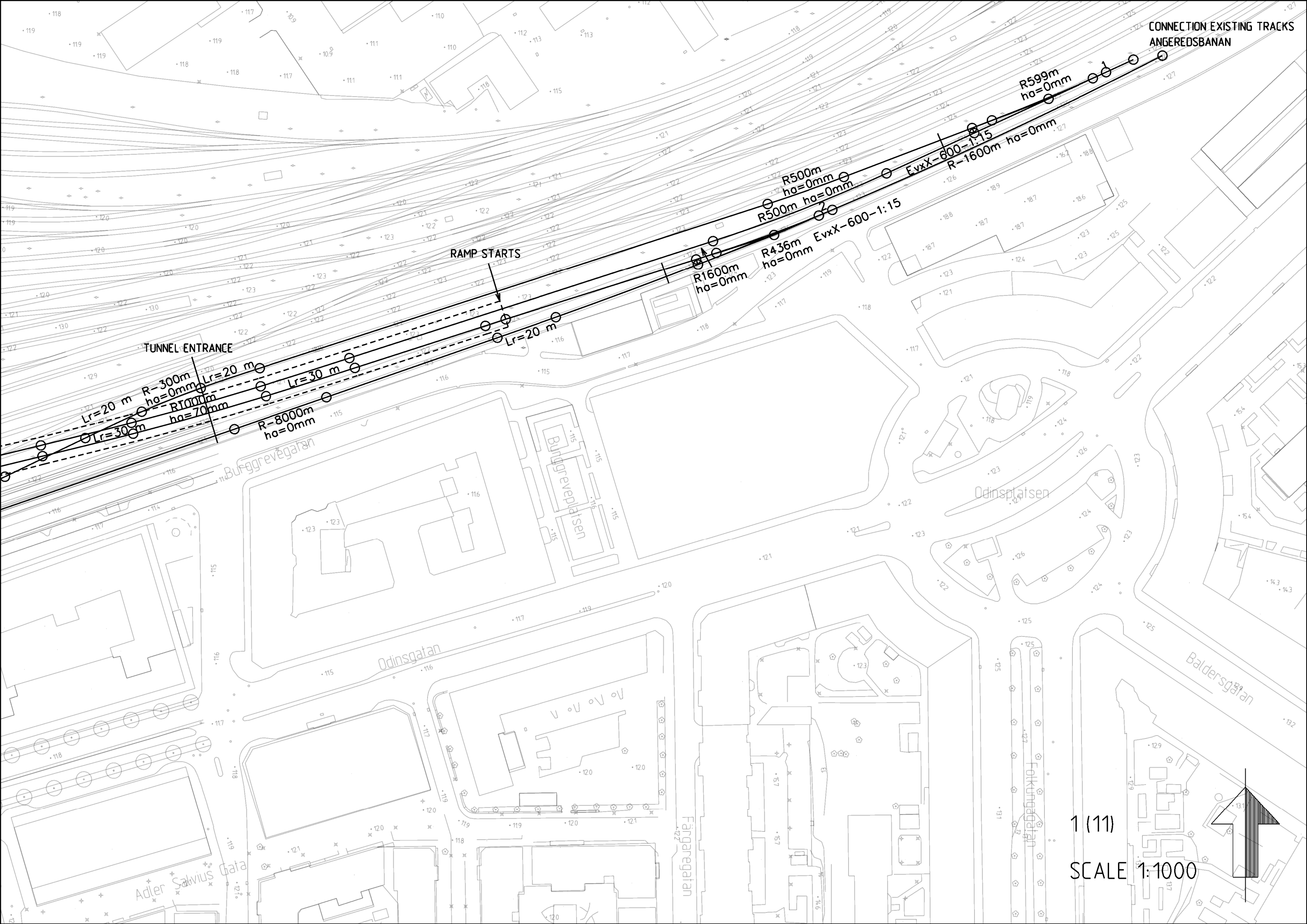


Figure A.VI-1 Overview map showing the page order of Appendix VI.

CONNECTION EXISTING TRACKS  
ANGEREDSBANAN



TUNNEL ENTRANCE

RAMP STARTS

Burggrevegatan

Odinsgatan

Baldersgatan

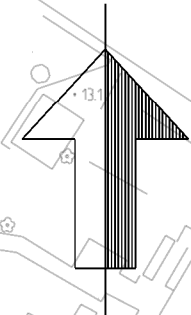
Färgaregatan

Folkungagatan

Adler Salvius Gata

1 (11)

SCALE 1:1000





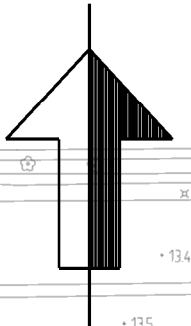


# STATION CENTRALSTATIONEN

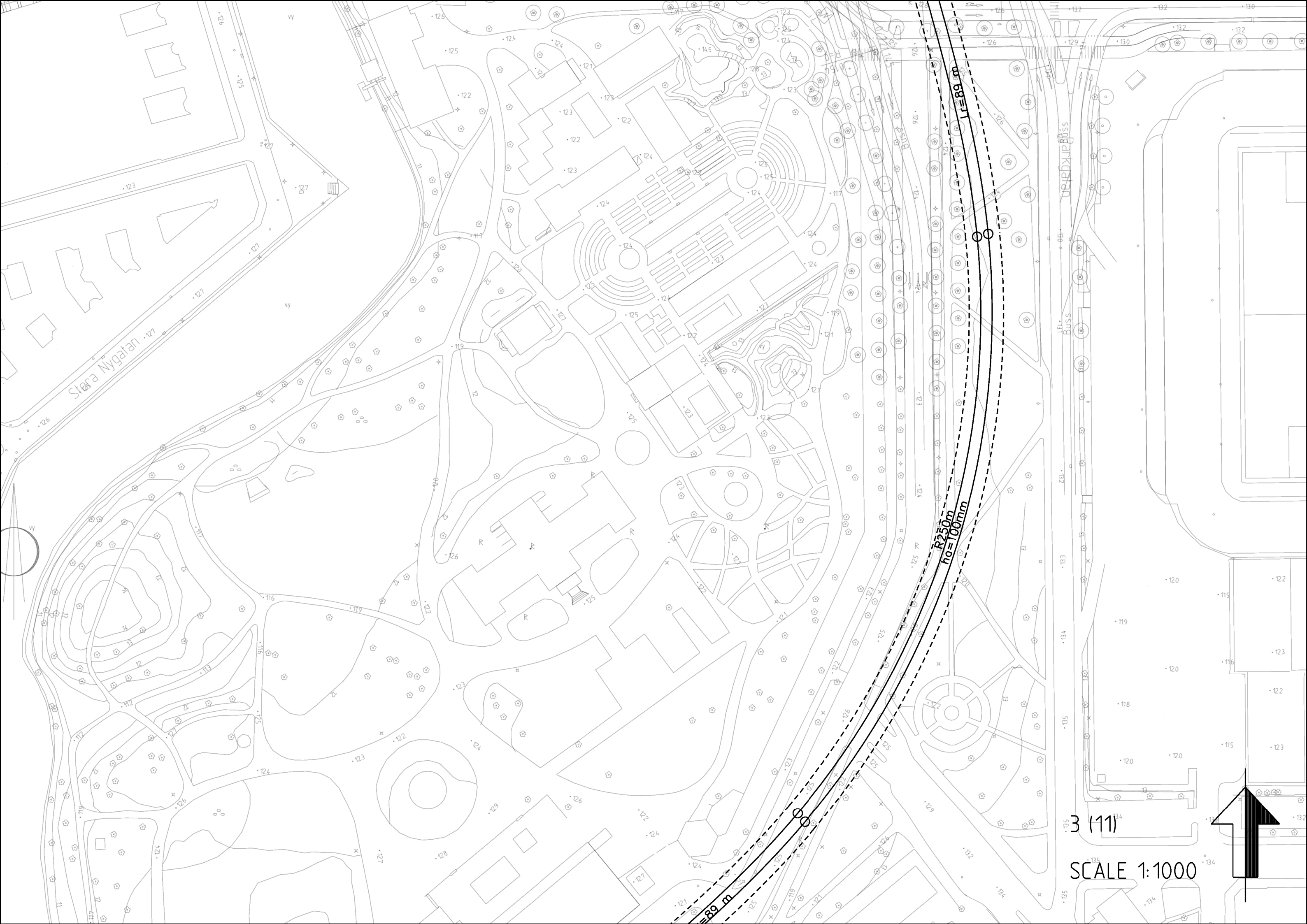
BANGÅRDSVIADUKTEN  
(EXACT POSITION AND DESIGN  
NOT YET DETERMINED)

2 (11)

SCALE 1:1000







Slåra Nygatan

Buss

Buss

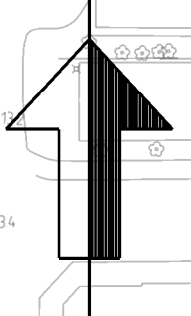
3 (11)

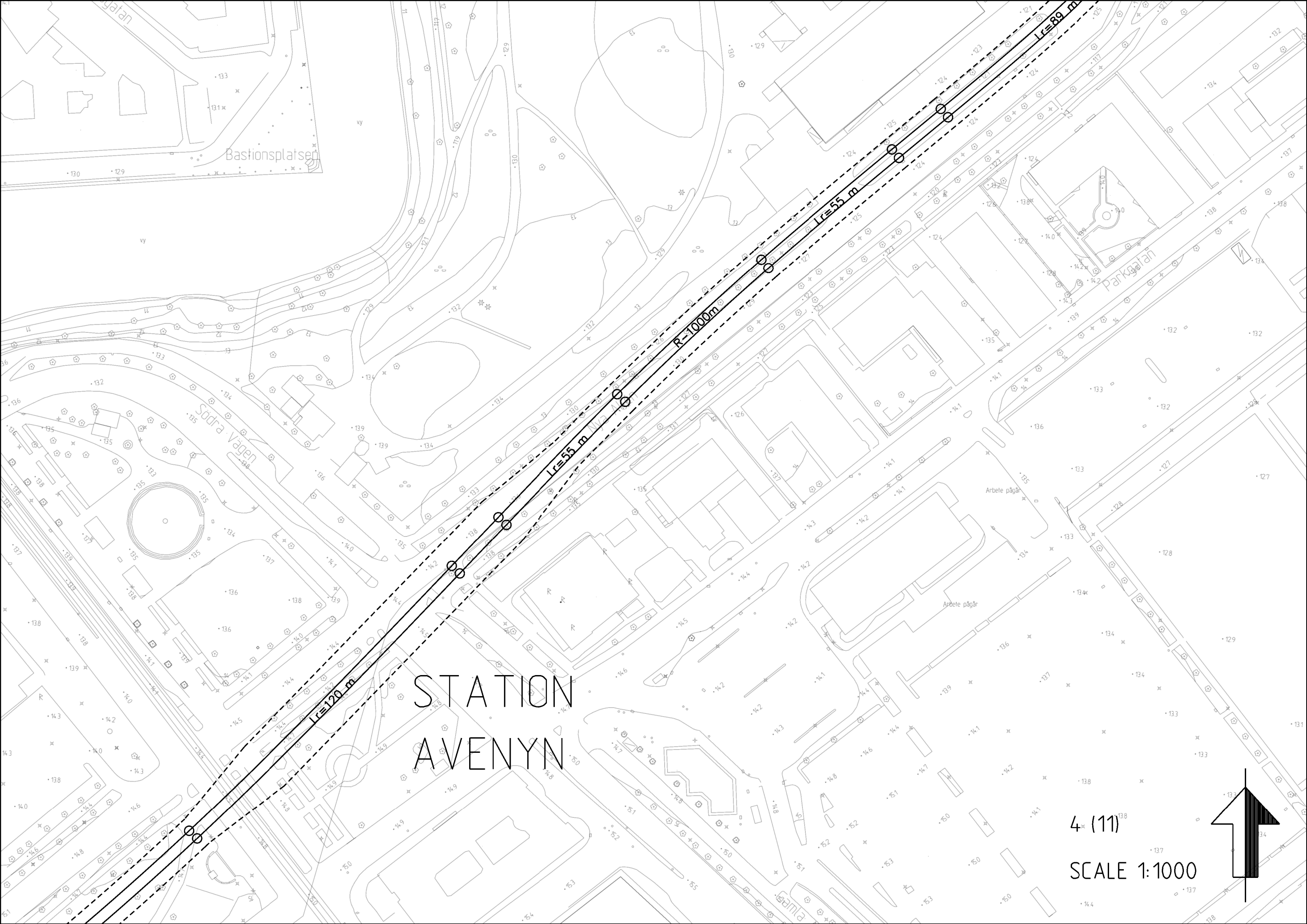
SCALE 1:1000

R=250m  
hc=100mm

r=80m

r=80m





Bastionsplatsen

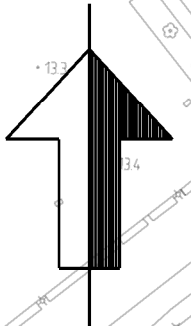
Södra vägen

Parkgatan

STATION  
AVENYN

4 (11)<sup>138</sup>

SCALE 1:1000



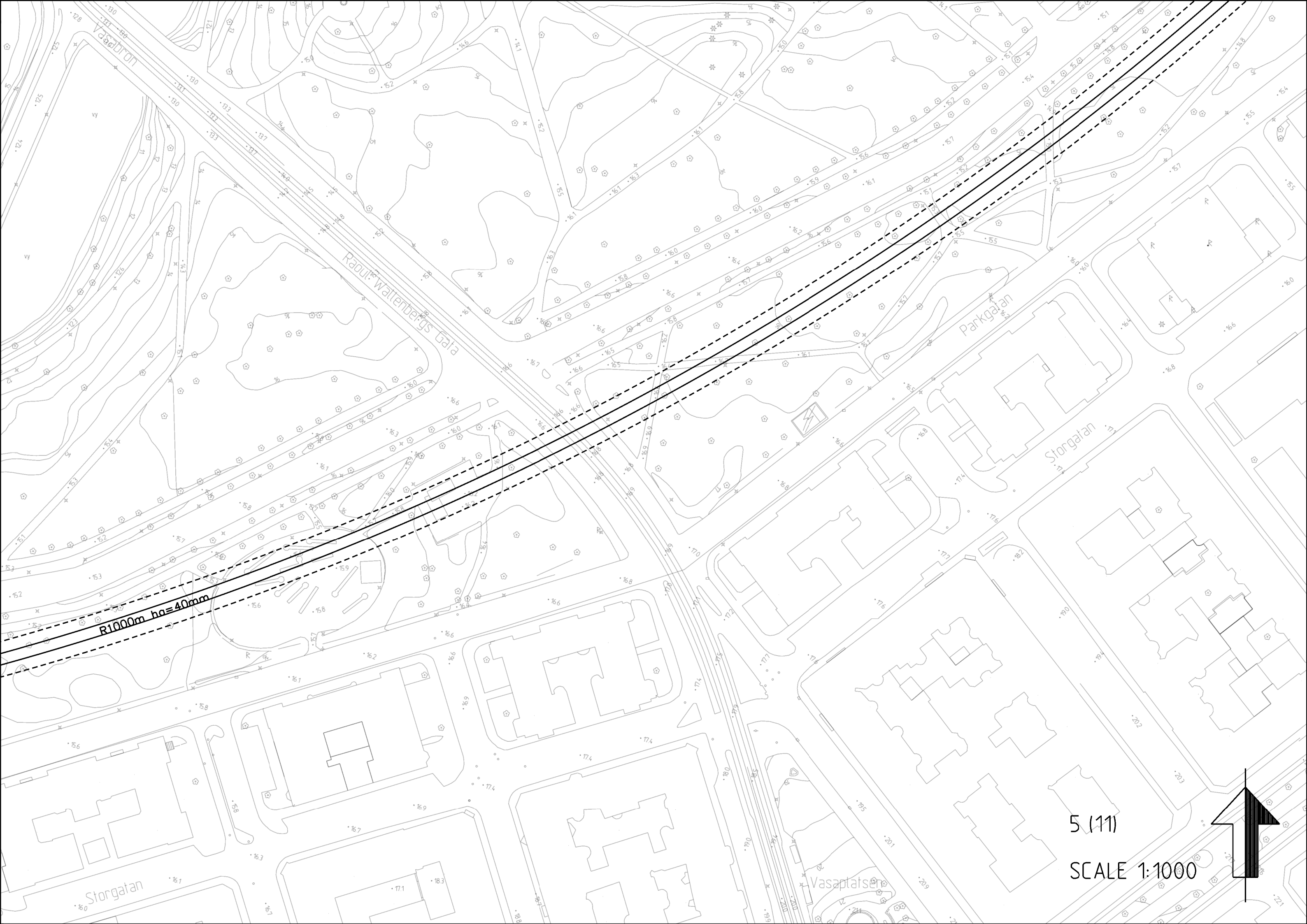
Lr=120 m

Lr=55 m

R=1000m

Lr=55 m

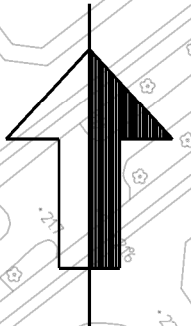
Lr=89 m

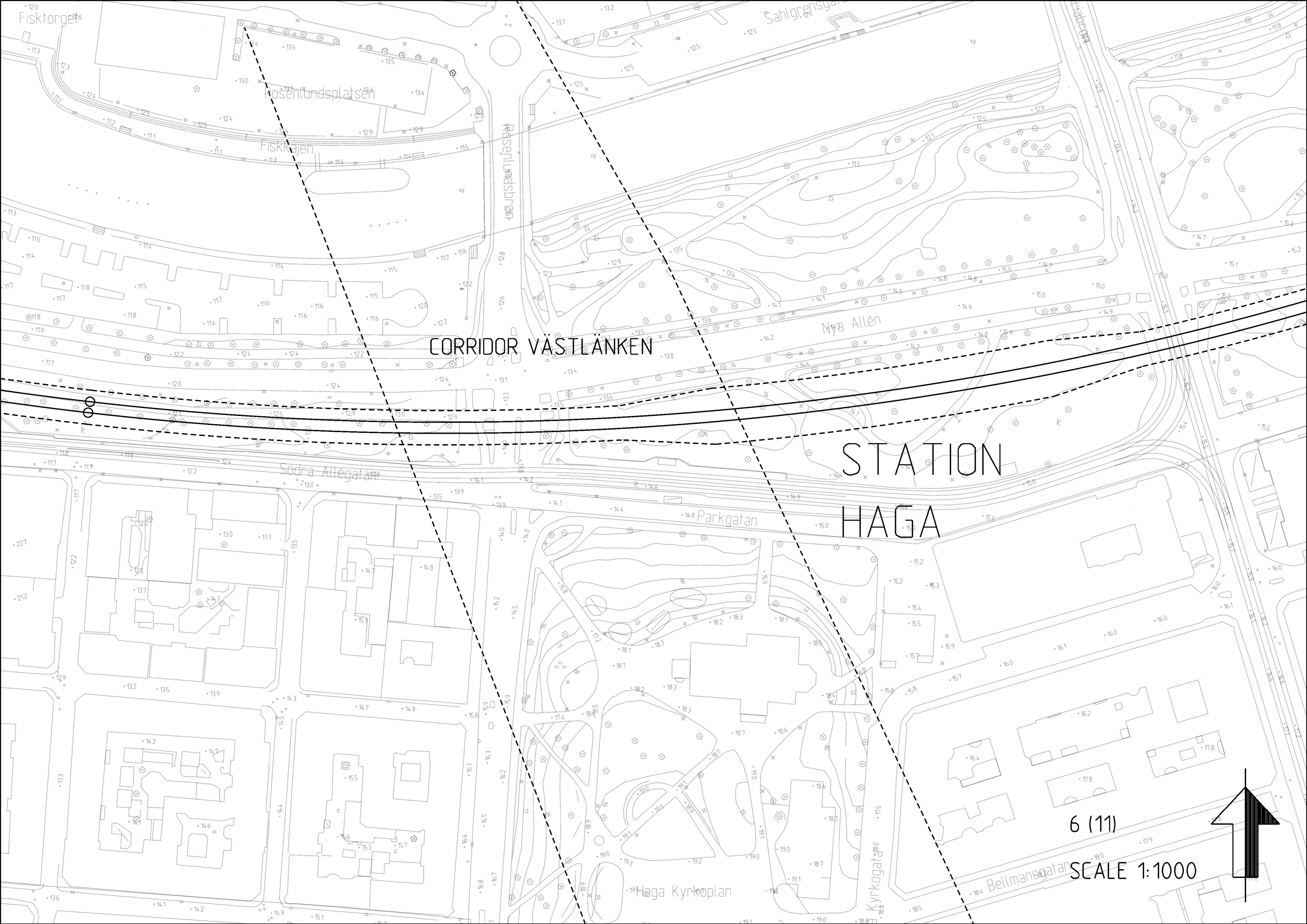


R1000m ha=40mm

5 (11)

SCALE 1:1000





Fisktorget

Sahlgrenska

Rosentundsplatsen

Fiskkajen

Rosentundsbron

CORRIDOR VÄSTLÄNKEN

Nya Allén

STATION  
HAGA

Södra Allégatan

Parkgatan

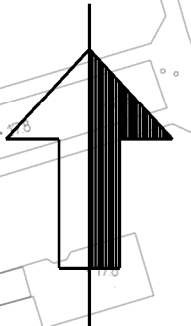
Haga Kyrkoplän

Kyrkogatan

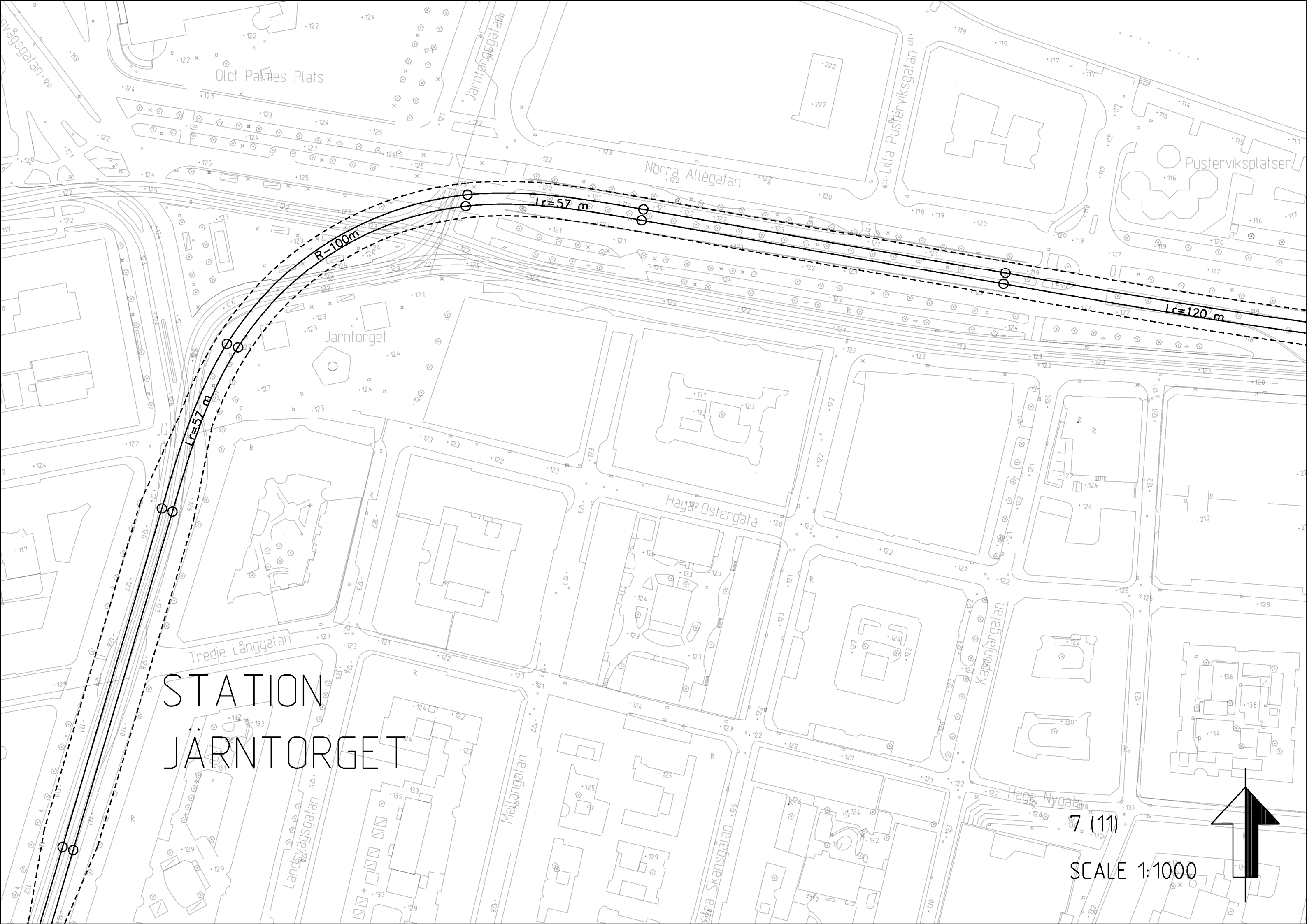
Bellmansgatan

6 (11)

SCALE 1:1000

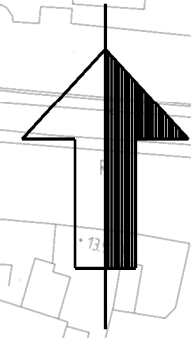




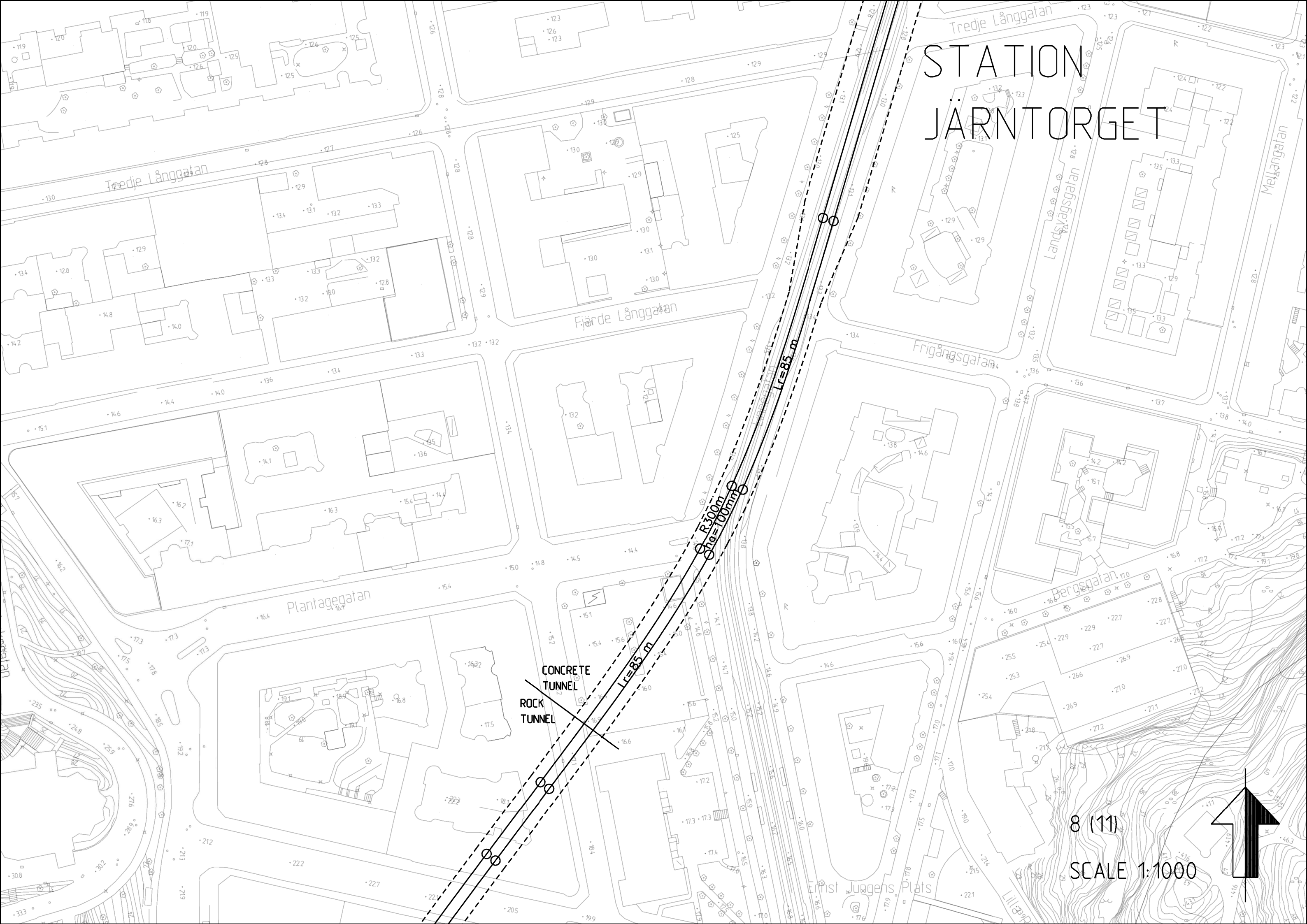


STATION  
JÄRNTORGET

7 (11)  
SCALE 1:1000



# STATION JÄRNTORGET



CONCRETE  
TUNNEL

ROCK  
TUNNEL

R=100m  
D=100mm

L=85 m

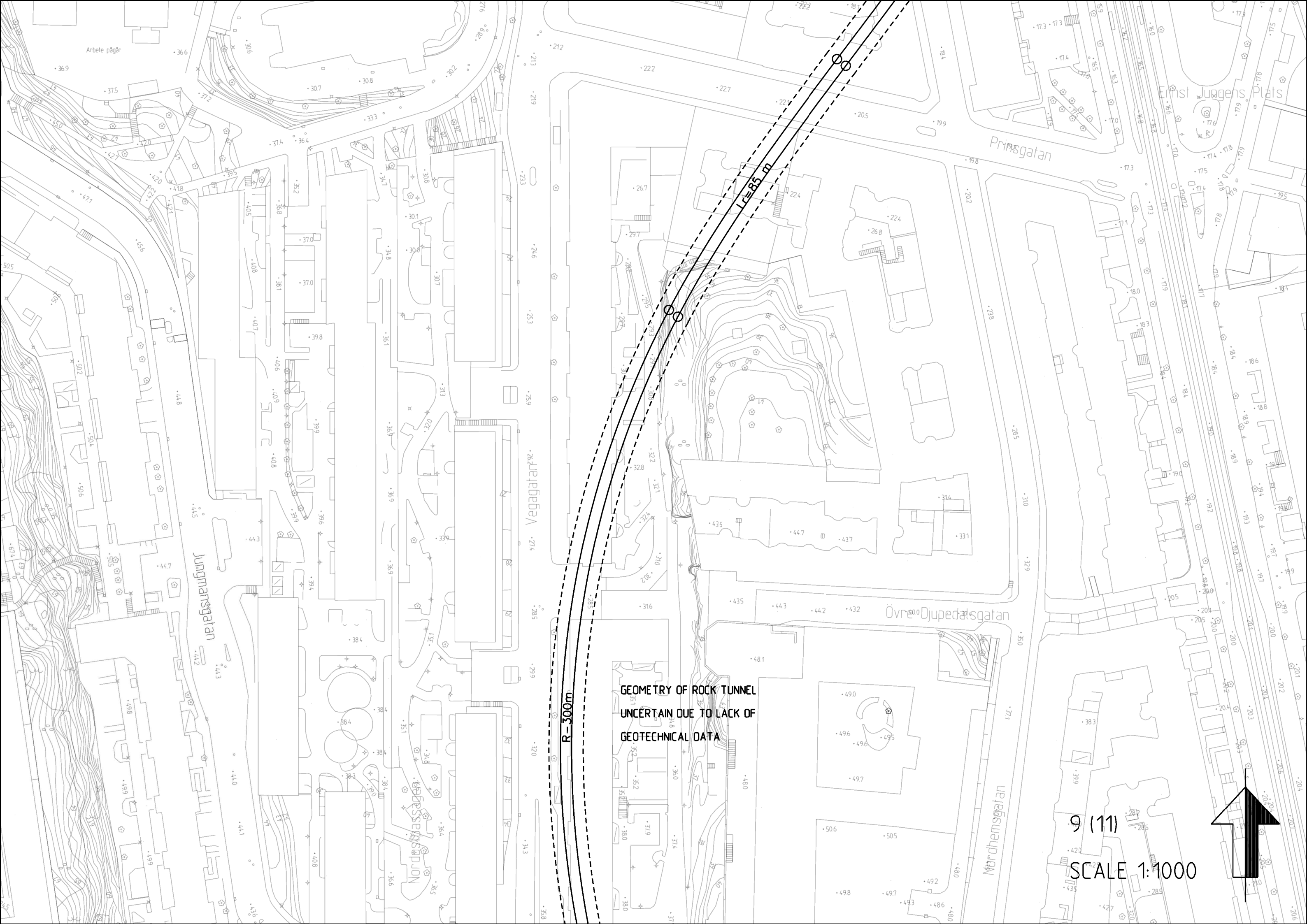
L=85 m

8 (11)

SCALE 1:1000



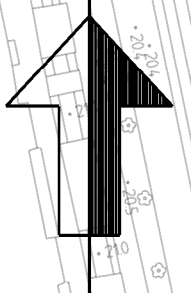


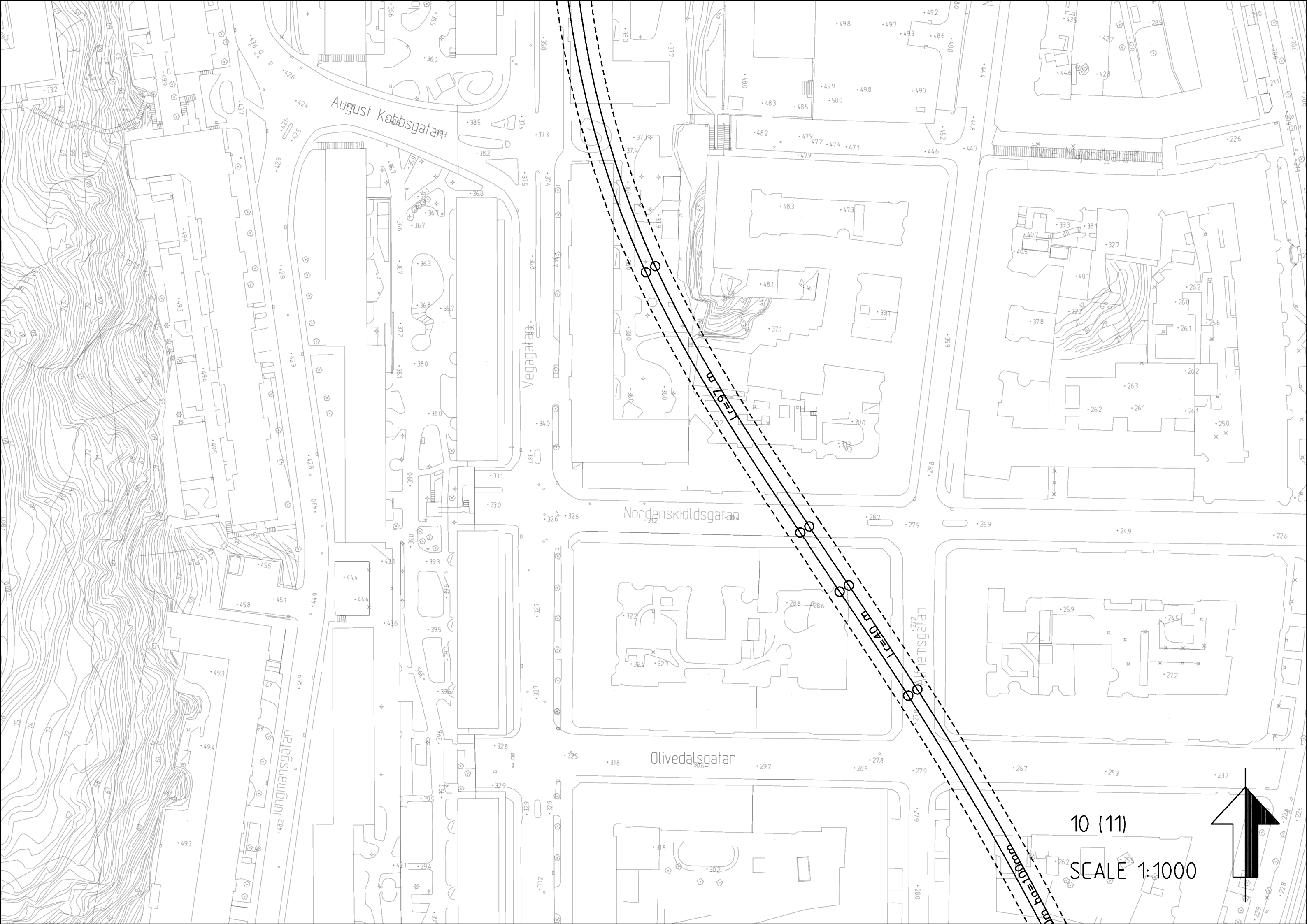


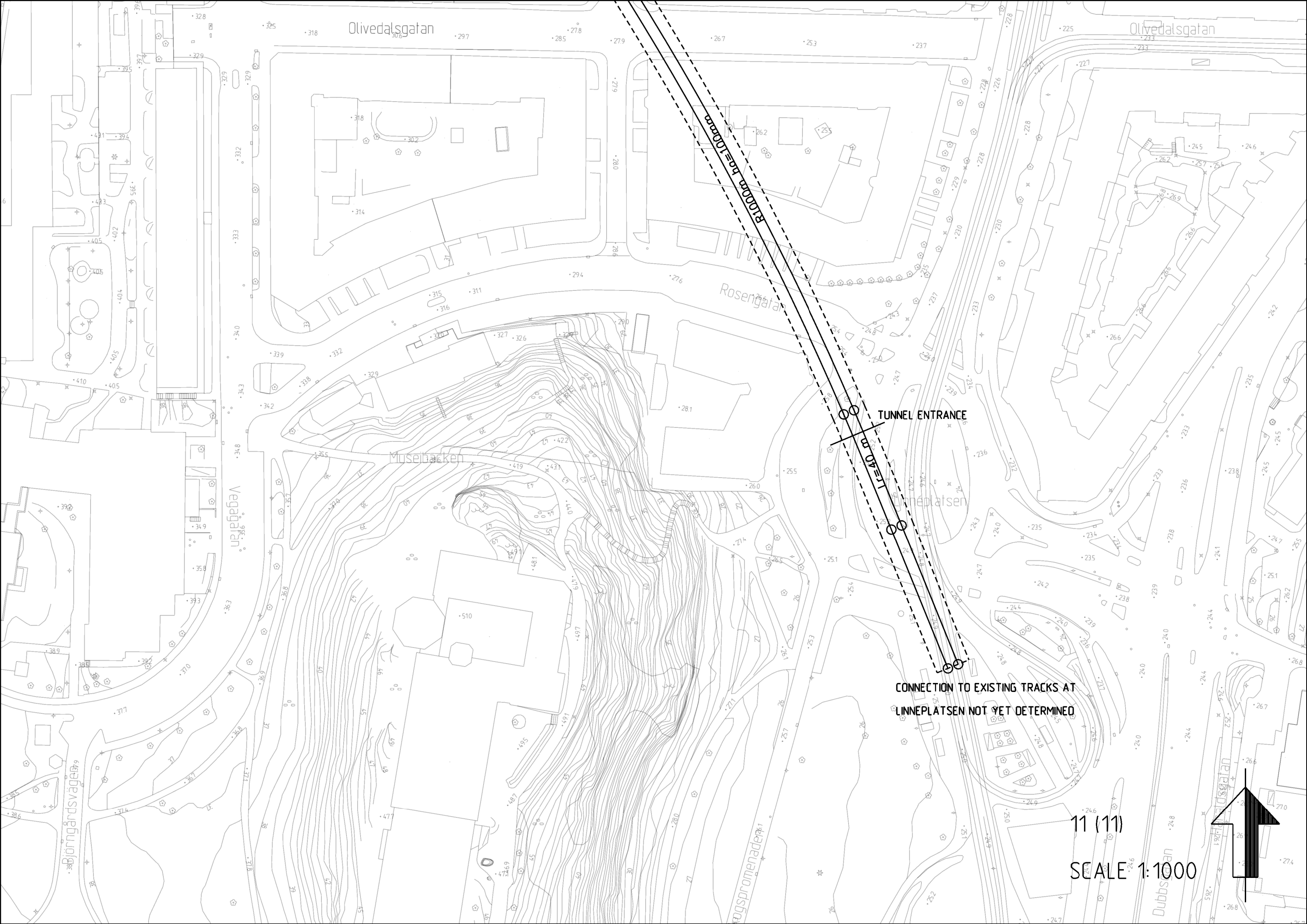
GEOMETRY OF ROCK TUNNEL  
UNCERTAIN DUE TO LACK OF  
GEOLOGICAL DATA

9 (11)

SCALE 1:1000







Olivedalsgatan

Olivedalsgatan

Rosengatan

Museibacken

Vegagatan

Björngårdsvägen

Rogspromenaden

Dubbsgatan

1100m på 100m

TUNNEL ENTRANCE

CONNECTION TO EXISTING TRACKS AT  
LINNEPLATSEN NOT YET DETERMINED

11 (11)

SCALE 1:1000

