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ARLANDA LINK - A NEW RAILWAY BENEATH ARLANDA AIRPORT IN STOCKHOLMS WESTERN, A TECHNICAL BLASTINGC HALLANG .

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ABSTRACT:The Arlanda link project is for the time being the most interesting project in Sweden, concerning rock and blasting technology.

The total amount of rock excavated beneath Arlanda airport comprises 800 000 m^3 divided in four parallell tunnels measuring a total length of 8,5 km, with a rock covering of only 5-15 m between the tunnel roof and existing terminal buildings.

A railway between Stockholm and Arlanda has been a priority for a long time. The goal is to connect a railway with the flying-network. The route between Stockholm Central station and Arlanda will be driven by a shuttle making a speed of 200 km/h and the trip will take only 19 min.

Three railway stations will be built directly beneath the terminals. Two of the underground stations are intended for the shuttle from Stockholm. From the stations one will be able to reach desired terminal by escalators and elevators.The third station, which will be placed beneath Sky-City, is intended for long distance and commuter trains.

The total estimated cost of the project is about 5 billion Swedish kronor and has both Swedish and foreign financiers. Arlanda Link Consortium (ALC), among others consisting of the two Swedish contractors NCC och SIAB, started the construction of the tunnels in the autumn 1995. The project will continue for four years.

Nitro Consult has made risk analysis to establish criteria and control of vibrations, scttlings and crack growth for buildings above the tunnel. Trialblasts with regression analysis and scaling law diagram have been carried out. Design and follow-up of the drill and loading patterns are also a part of the control.

Very sensitive computer equipment is installed inside the terminals and Sky-City which among other things control the close air traffic.This equipment has been vibration isolated to stand against the vibrations from the blasting rounds and thereby avoiding any disastrous accidents.

An extensive monitoring and supervising program has been installed for safe control. Via UVS Remote, telephone modem and UVS 1500 Vibration Time History Rccorder vibrations from several blasting faces can be presented directly via computer to both the site offices and to our own head office 50 km away.

This means that one quickly can decide if there is need for changes in the drill and charging plans and thereby actively plan the blasting in a safe and economical manner.

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1.BACKGROUND

One of the most interesting projects in Europe, regarding blast and vibration technique, is for the time being under construction beneath Arlanda airport (fig.1 and 2).

Arlanda airport, which is situated 50 km north of Stockholm, the capital of Sweden, has during the last five years expanded and even become a large international airport. As the bus and car traffic between Stockholm and Arlanda has increased radically, one has for a long time discussed a railway. The goal is to connect the railway system with the flying network, thus giving people a far better commute from an environmental, speed, timeliness and comfort point of view.

The journey between Stockholm and Arlanda will only take 19 minutes with the shuttle, which will have a speed of 200 km per hour. Besides the shuttle, both long distance and commuter trains will stop at Arlanda. Three stations will be built directly beneath the terminal buildings. Two are intended for the shuttle from Stockholm Central station. The third station, which will be placed beneath Sky City, is intended for long distance and commuter trains from other cities in Mid Sweden.

By using escalators and lifts directly from the underground stations, the travellers will be able to reach the terminals easily and comfortably.

2.ORGANIZATION AND FINANCING

In August 1994 Arlanda Link Consortium (ALC) won the bidding to build this project and also the task to finance the Arlanda Link and run the shuttle (fig.3).

Arlanda Link Consortium (ALC) consists of two Swedish contractors NCC och SIAB and two Brittish, GEC ALSTHOM and Mowlem and the Swedish Vattenfall.

NCC and SIAB are responsible for the blasting and rock construction. GEC ALSTHOM deliver the shuttle train, electrical signal and tele communication systems and Mowlem deliver and install the track and gears.

Arlanda Link is a so called BTO-project (Build, Transfer and Operate). A-Train started the client company A-Train Ltd who will build The Arlanda Link mainly with private money. The ownership will be taken over by the state as soon as the railway is finished. In exchange A-Train Ltd can keep the income from ticket sales during the first 45 years by running the shuttle between Stockholm Central station and Arlanda.

The total cost for the project is predicted to be 5 billion SEK where about 2 billion SEK are the costs for the blasting work.

3.SITE CONDITIONS

The total amount of rock which will be excavated by blasting is 800 000 m^3 divided in four parallell tunnels with a total length of 8.5 km. The rock layer between the tunnel roof and the terminal buildings is only 5-15 m (fig.4).

Two of the tunnels are singletrack tunnels of 55 m^2 and two are doubletrack tunnels of 90 m^2. The three stations, which will have an area of 200 m^2, have a length of 200 m and a span of 22 m.

Since these blastings are so close and beneath a large international airport it requires very strict security measures and safety steps where communication and information together with rigorous control is very important.

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From earlier excavations at the Arlanda area, where blastings for tunnels and open pits have been made, one has learned that the geology varies from hard massive granodiorite to fissured soft mica schist with clay minerals in the fissures. Since the rock covering is often only 8 m or even less, with heavy loads from the above buildings through pillars, a rigorous control program has been worked out to keep the safety standards on the highest level.

4.RISK ANALYSIS

Nitro Consult became engaged at an early stage during the preplanning to carry out risk analysis. This means that Arlanda airport has been investigated regarding construction and the foundation of the buildings.

When taking into account the construction and material of the buildings with the foundation and the distance to the blasting, you have guidelines for vibration restrictions according to the Swedish Standard SS 460 48 66. This standard, which has existed since 1989, is based on long practical experience and knowledge from earlier blasting projects in Sweden and is now used in all projects where blasting occurs close to buildings and other structures. These guidelines help the consultants to establish the permitted vibration criteria for each respective object.

However, it is not only the buildings that regulates the size of the blasts. At the airport, there are also computers, electrical stations and other sensitive equipment which simply must not break for obvious safety reasons.

The risk analysis hereby gives:

- Information and contacts
- Vibration criteria for buildings and equipment
- House inspection
- Control measurements such as:
  - Vibration measurement and analysis
  - Crack growth measurement for buildings above the tunnel
  - Settling control of buildings and and structures
  - Extensiometer measurement in rock
  - Convergence measurement in tunnels
  - Noise measuring

All these controls are worked out in quality assurance and control plans where the measuring points, evaluations and reports are made continuously for the contractor, engineering consultant and owner of the buildings.

When it comes to computers and other sensitive equipment, the vibration restrictions are given in acceleration levels as low as 0.3 g (3 m/s^2). At an incoming vibration frequency of 100 Hz, it means only 3 - 4 mm/s as compared with 80 mm/s which is the limit of the buildings at the distance of 10 m.

Computers and other sensitive equipment are vibration isolated to manage the vibration criteria of 0.3g, thereby making blasting possible. This means that the equipment is lifted up on shock absorbers that filter the vibration level up to 95-98% in the best cases.

To isolate the sensitive equipment from vibrations means in most cases that the buildings will be the dimensional factor instead of the equipment. It is difficult to understand that a project of this magnitude would otherwise technically become impossible and take too long to fulfil.

The most complicated isolation was a relay station of 10 000 kgs which was lifted up with liftjacks and thereafter placed on shock absorbers.

S.I.T.A (*Société Internationale de Télécommunications Aéronautiques*) is the

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heart of the airport where all communication occurs via computers. This section of computers was lifted up and detached from the floor with dampening isolators.

5.HOUSE INSPECTION - CRACK GROWTH MEASURING

Before the blasting work started, all buildings and constructions have been inspected by documenting all existing cracks, settlement and so on. The procedure for this is stated in a relatively new Swedish Standard SS 460 48 60.

A few relatively big existing cracks have been noted in the central building Sky City located between terminal 4 and 5, which have appeared after it was completed in 1994.

These cracks have arisen partly because of movements, temperature and/or settlement in the ground (fig.5). It is therefore very important to follow up these movements during the time that this project runs. The crack growth measurement registers the movement both horizontally and vertically with a precision at 1/10 mm.

Ten continuous measuring stations, which are positioned at different places are read after every blast.

6.PRECISION SURVEYING, EXTENSIOMETERS AND CONVERGENS MEASUREMENTS.

The terminal buildings and Sky City are all located on solid rock, except a minor area beneath Sky City. A primaty concern is how the buildings will be affected when horizontal and vertical movements occur in the rock mass when rock excavation proceeds.

Tensions in the horisontal direction are larger than in the vertical direction, which has led to that some buildings, heaving at first and later settle back to some extend. The precision surveying has also confirmed that some buildings heav as high as 5 mm (fig.6) and the tensions in the rockmass beneath the terminals are maximum 3-4 mm (fig.7).

Convergens measurements show that the tunnelroof in the stations settles 0.4-2.3 mm in average after blasting the pillar between the tunnels (fig.8).

7.BLAST AND VIBRATION CONTROL

Before the tunnel blasting started beneath the buildings, the project started with the blasting of the access tunnels at a relatively safe distance. During that period several trial blasts were performed. Simultaneously detonating charges, distance between blast and building and registered vibration levels gave valuable information to carry out regression analysis (fig.9). To be able to get this information it was necessary to make carefull documentation and follow-up of the loading and ignition patterns and compare that with the time history recordings using accurate separated intervals.

With this information a scaling law diagram can be plotted. The scaling law diagram calculates the line which corresponds to the formula $v=A*(R/Q^{0.5})^{B}$. Three confidence levels are given i.e. 50%, 84% and 98%. The 84% confidence line is recommended in this project.

By calculating the scaling factors where these lines reach a chosen limit, the loading table can be constructed with maximum possible advance per round corresponding to vibration criteria and simultanously detonating charge. This analysis gives the loading and distance tables, which are continuously used for new drill, load and ignition patterns. To document the vibration levels Nitro Consult's vibration monitor UVS 1500 is used (fig.10). This instrument is used together with an UVS

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REMOTE system for continuous data transferring via telephone modem.

Data transfer can be performed and presented directly on the PC's in the site offices as well as on our own PC's at the head office 50 km away. With this data transfer each responsible site manager can directly after the blast read the recordings from forty measuring points with full time history registration and thereby compare that to the ignition pattern which gives the maximum vibration interval.

This means that one quickly can decide if changes in the charge and ignition patterns are needed.

The tunnel blastings are carried out in a changing geology which means that continuous updating with regression analysis must be done. Luckily enough the mica schist appears to be very favourable from vibration point of view when the schistosity falls very flat and therefore has a dampening affect on the propagation velocity vertically.

The round is drilled with 45 mm diameter drillbits and loaded with 32 mm diameter Dynamex in the bottom and ANFO or Emulet 50 in the column.

For the contour holes and nearest stoping holes the charges were reduced to keep the damage zone at a maximum depth of 0.3 m. The contour holes were loaded with 17 mm diameter Gurit or Nitro cord and the holes nearest contour with 22 mm diameter Emulite 100. The maximum hole depth is 5.2 m which means maximum 5.2 kgs/hole.

To be able to blast in some critical parts with a vibration limit of 80 mm/s it is nessecary to make an ignition pattern with as few instantaneous intervals as possible (fig.11). The ignition system NONEL LP from Nitro Nobel is used. The connecting pattern for a tunnel round is also delayed in five parts with Nonel Unidet UB0, UB42, UB67, UB109 and UB176 caps where the figures stand for the delaytime in milliseconds.

By using this method only five holes are ignited at the same time in a tunnel round of total 138 holes. The scattering in time between these five holes means that the simultanously detonating charge is theoretically only from one of the holes. The advance per round is then the next step to take, in order to reduce the charge.

To manage to blast the tunnels with big span widths and also to be sure of the stability, blasting is often made in two half sections where one half face is behind the other. The other way, which is mostly done for the doubletrack tunnels of 90 m^2, is to blast a pilot tunnel in the middle and then blast the stope to full width afterwards (fig.12).

The stations, which have a span of 22 m and a total area of 200 m^2, must be blasted in three sections. First two paralell tunnels, with a width of 7 m, then afterward the pillar in the middle which has a width of 8 m (fig.13).

8.NOISE MEASURING

The blast and the drilling machines have also created disturbing noise through the rock up to all the hotel rooms in Sky City. Special measuring has been made upwards in different levels in the buildings to compare one or several drilling machines. The noise level from a blast has also been a problem to solve as it sometimes wakens the guests. The best way to solve this is good information and to avoid blasting during the night.

9.PRESENT TIME

In August 1997 the blastings were finished and in autumn 1998 the new shuttle will be in operation.

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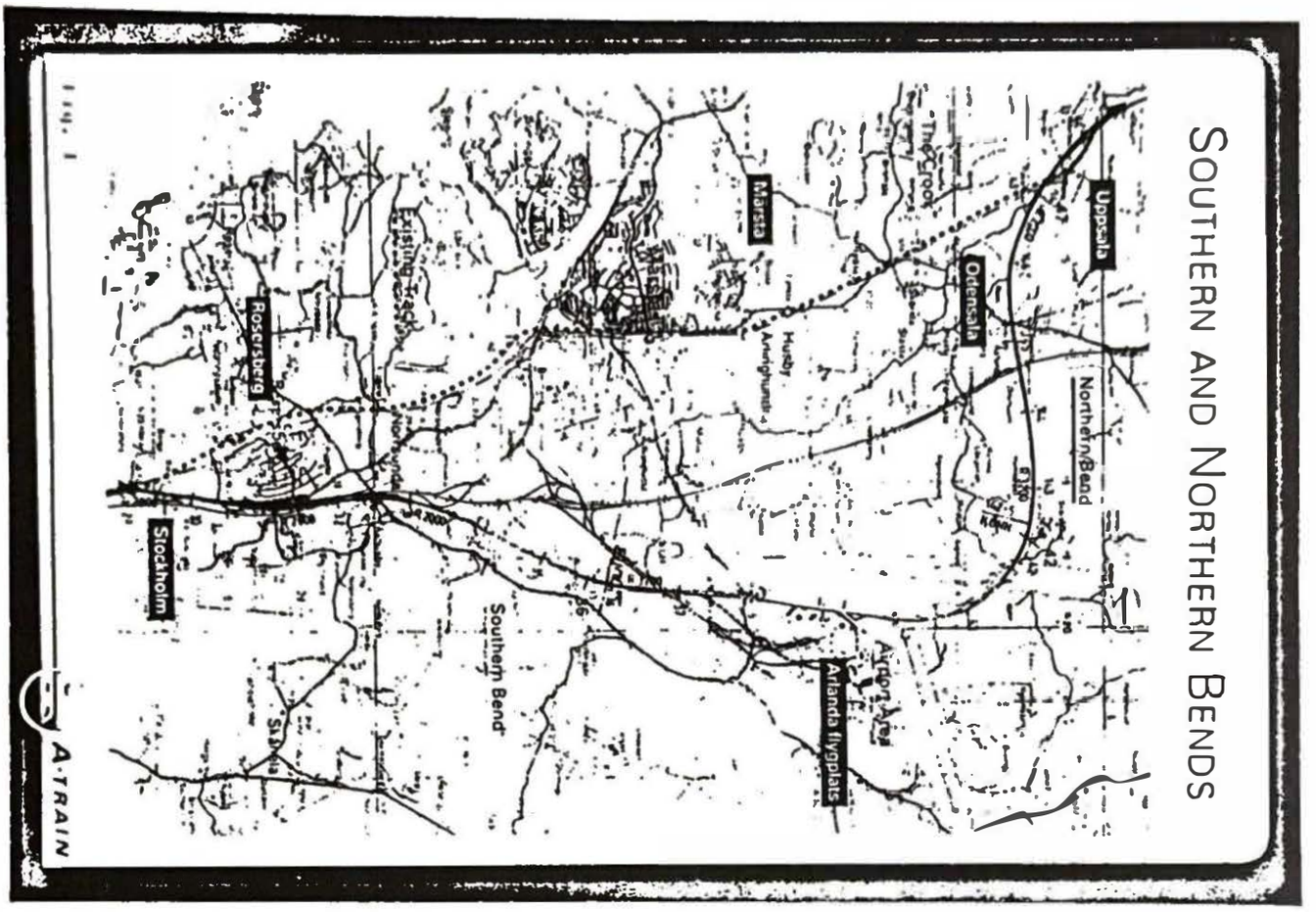

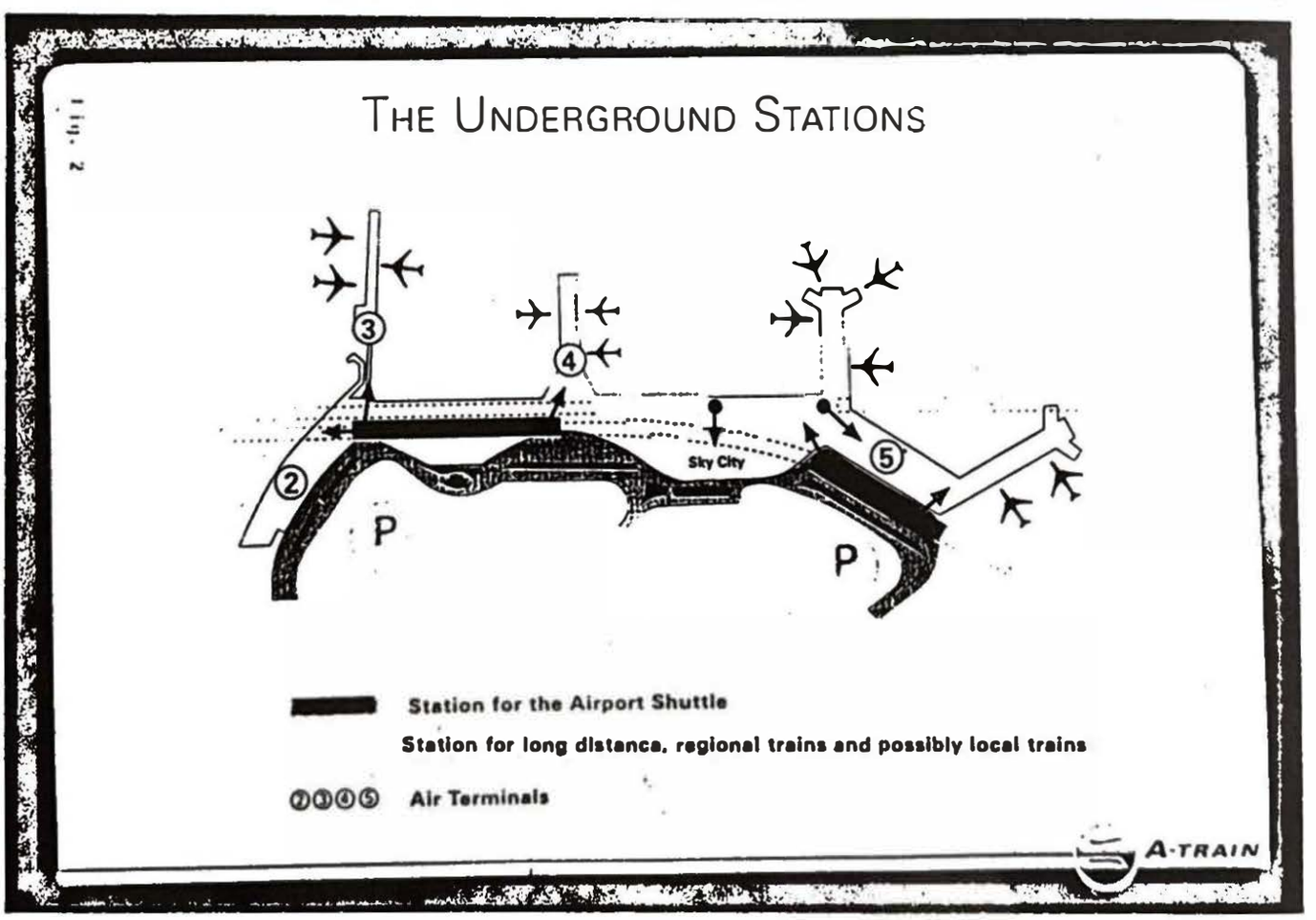

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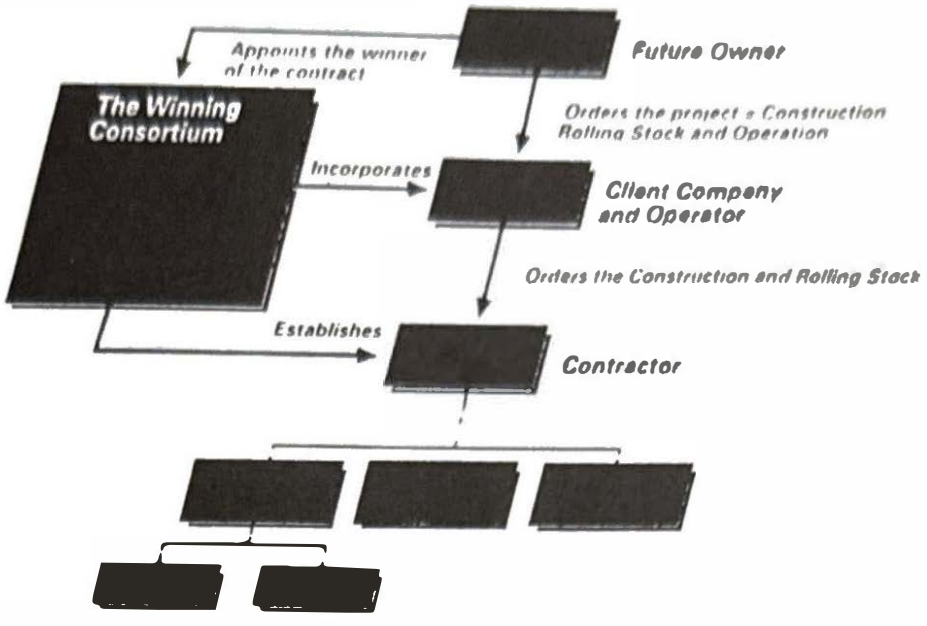
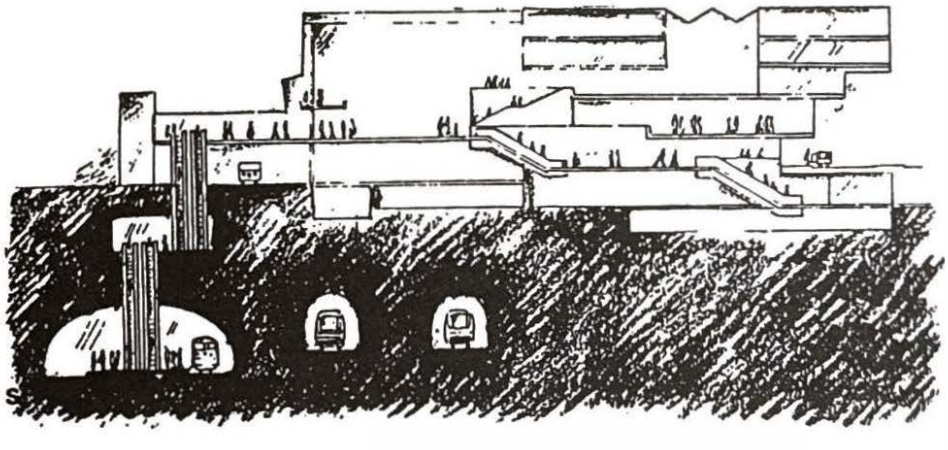
PROJECT STRUCTURE



A-TRAIN

FACILITIES UNDER SKY CITY



A-TRAIN

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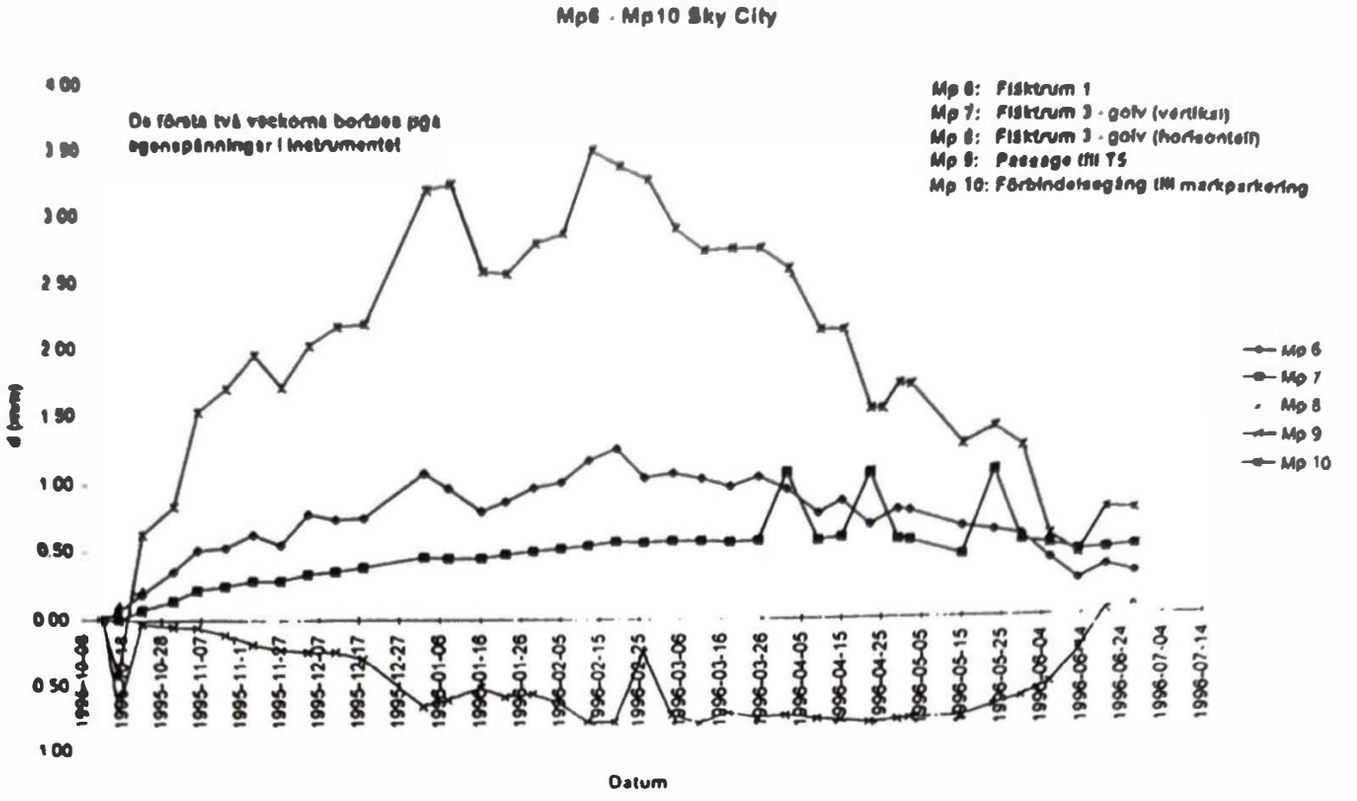

Fig. 5 Crack growth measuring in Sky City

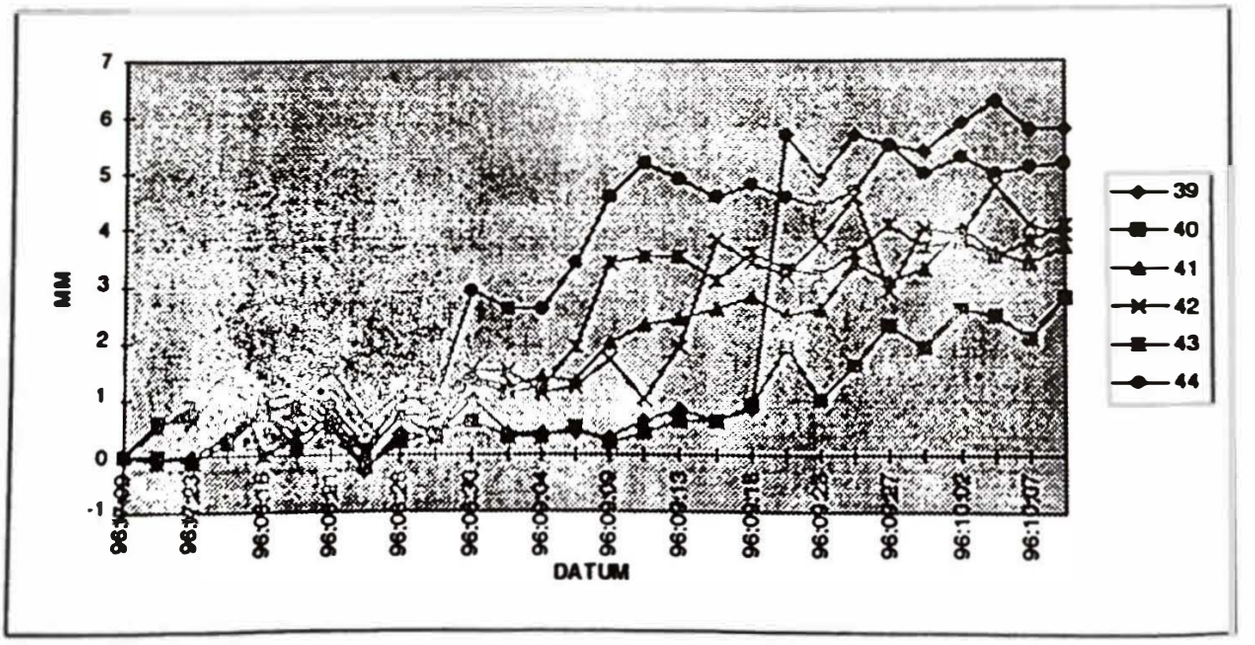

Fig. 6 Precision surveying at Terminal 2

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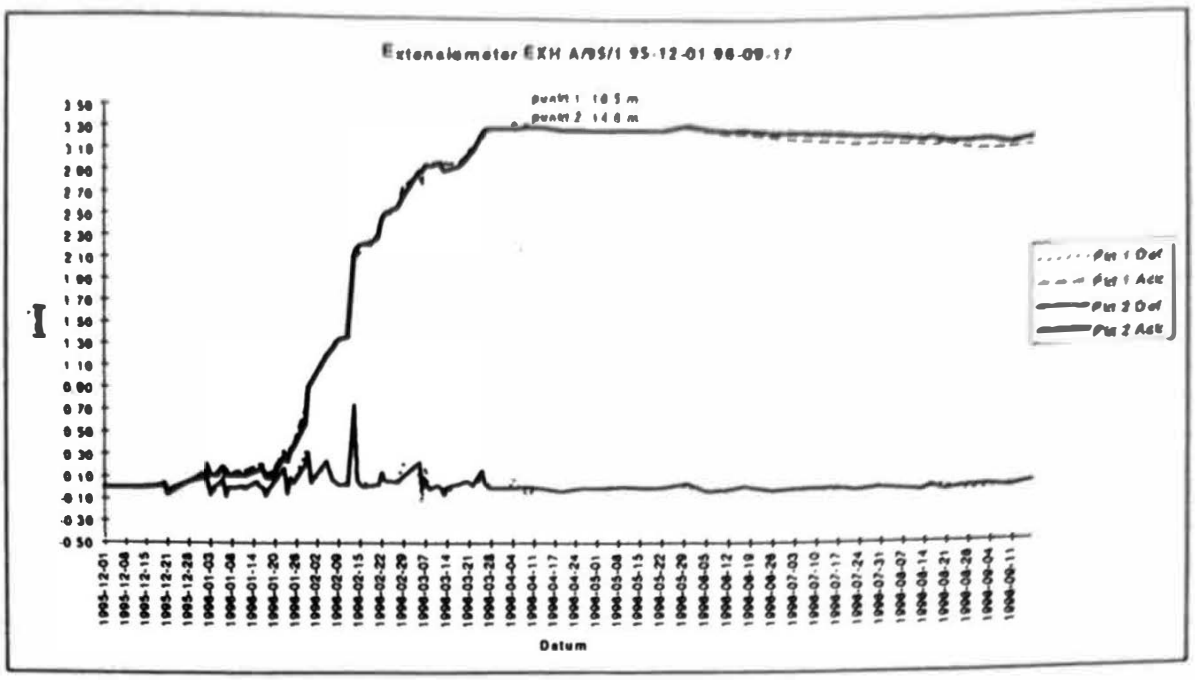

Fig. 7 Extensiometer measuring in rock mass beneath the terminals

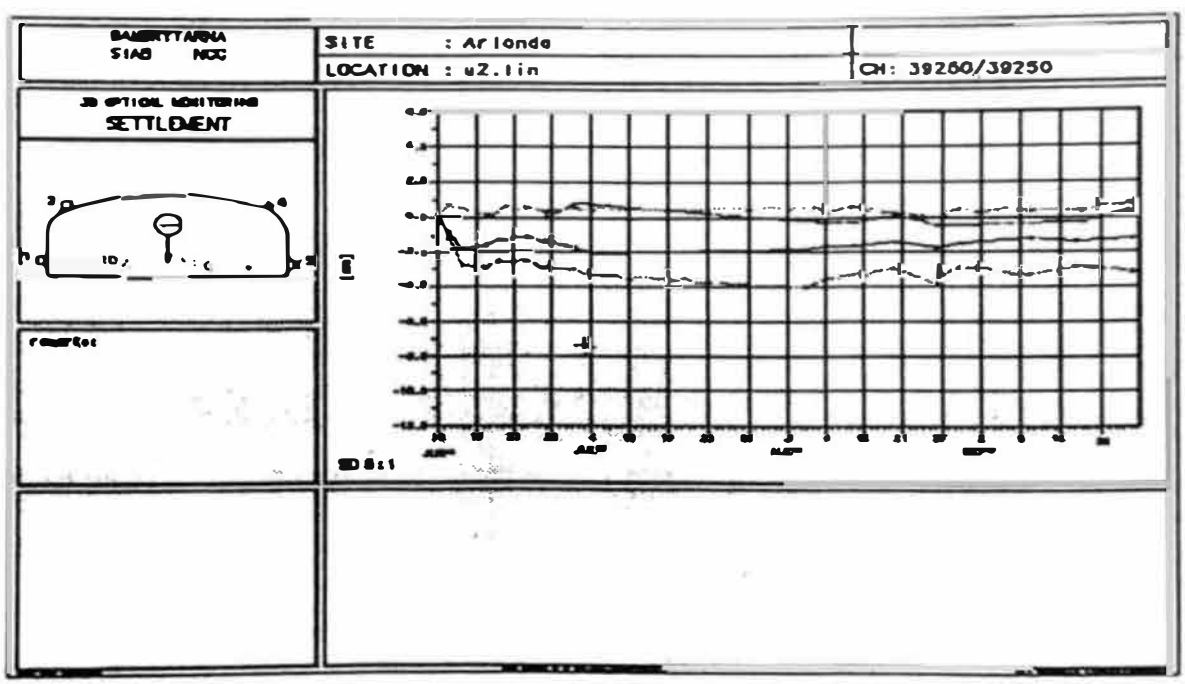

Fig. 8 Convergens measurements in shuttle station

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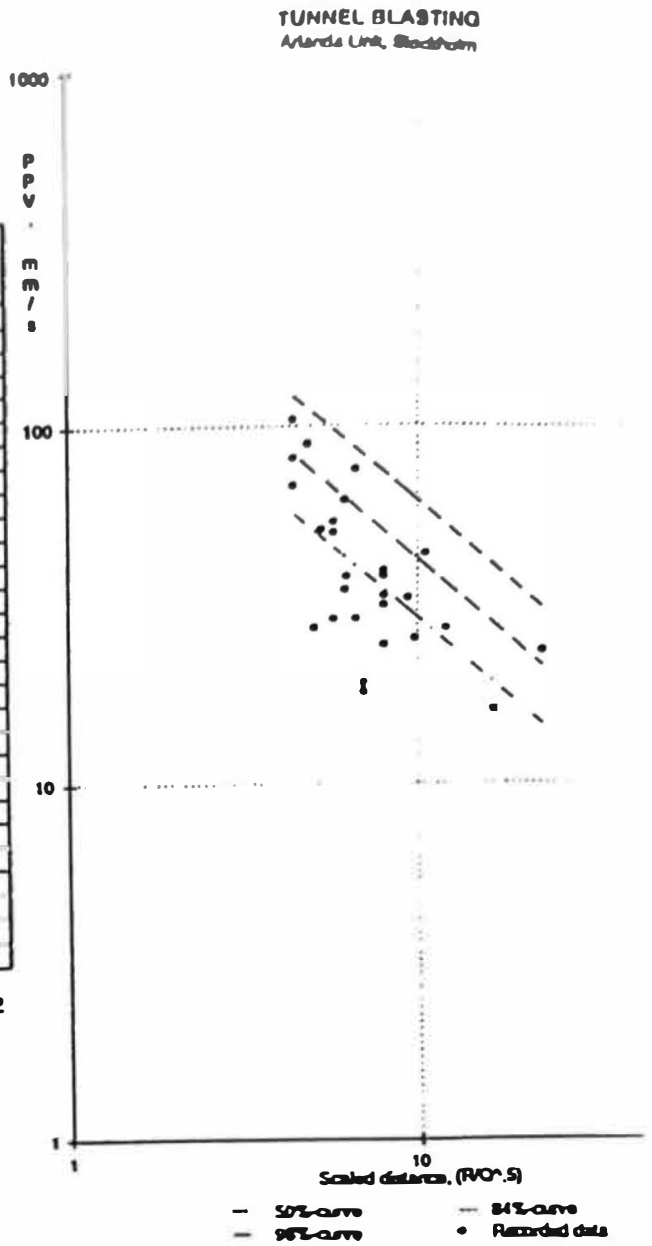
Nitro Consult AB

Tunnel Blasting
Arlanda Link, Stockholm
Shuttle tunnel 2
Regression anlysis

Instantaneous Delay Weight, kg	Distance m	Peak Particle Velocity, mm/s	Scaled Distance
5,0	12,0	51,5	5,4
5,0	13,0	54,0	5,8
5,0	14,0	62,0	6,3
5,0	16,0	18,2	7,2
5,0	18,0	33,5	8,0
10,0	20,0	38,0	6,3
5,2	24,0	44,0	10,5
5,0	27,0	27,2	12,1
5,0	37,0	16,1	16,5
5,0	13,0	50,5	5,8
5,0	15,0	29,0	6,7
5,0	18,0	39,5	8,0
5,0	51,0	23,5	22,8
5,0	14,0	35,0	6,3
5,0	15,0	75,5	6,7
5,0	18,0	38,0	8,0
5,0	16,0	19,3	7,2
5,0	10,0	81,5	4,5
5,0	11,0	89,0	4,9
5,0	10,0	104,5	4,5
5,0	18,0	24,5	8,0
5,0	10,0	68,5	4,5
3,8	10,0	27,5	5,1
5,0	18,0	31,6	8,0
5,0	13,0	29,0	5,8
5,0	21,0	33,0	9,4
5,0	22,0	25,5	9,8
5,0	22,0	25,5	9,8

N=28 224.12

PPV=A*(R/Q^.5)^B
B= -0,84
A= 201,49
S= 0,16
A(84)= 293,7
A(98)= 428,0



Loading table

Permitted PPV
PPV = 80 mm/s

Instantaneous Delay Weight for Different Confidence level

Distance, m	50%	84%	98%
10,0	11,0	4,5	1,8
15,0	24,8	10,1	4,1
20,0	44,2	18,0	7,3
25,0	69,0	28,1	11,4
30,0	99,4	40,5	16,5

Fig. 9

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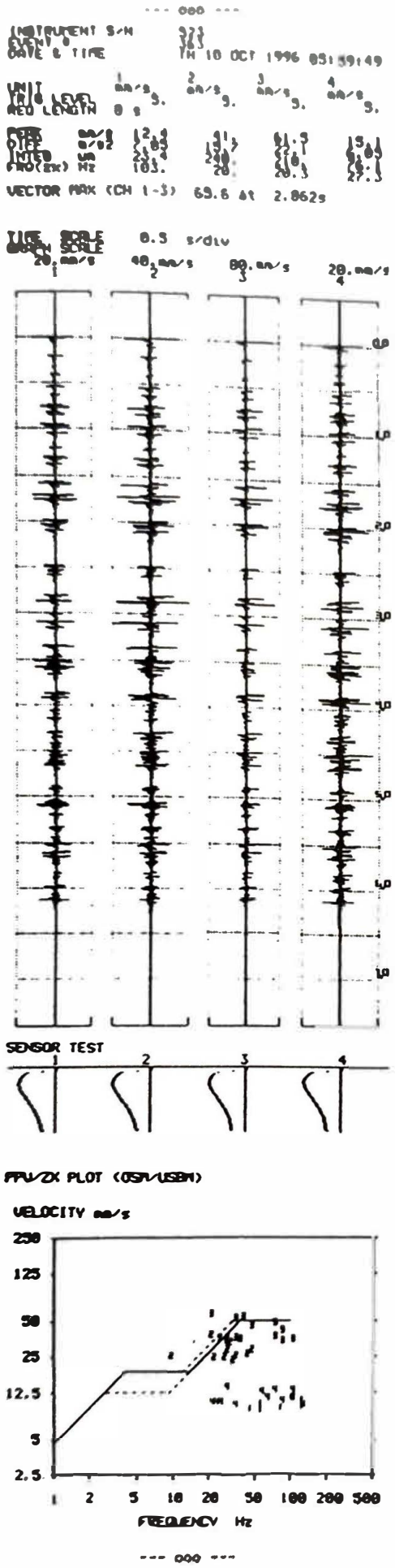

Fig. 10

Vibrations registration from blasting of the shuttle station

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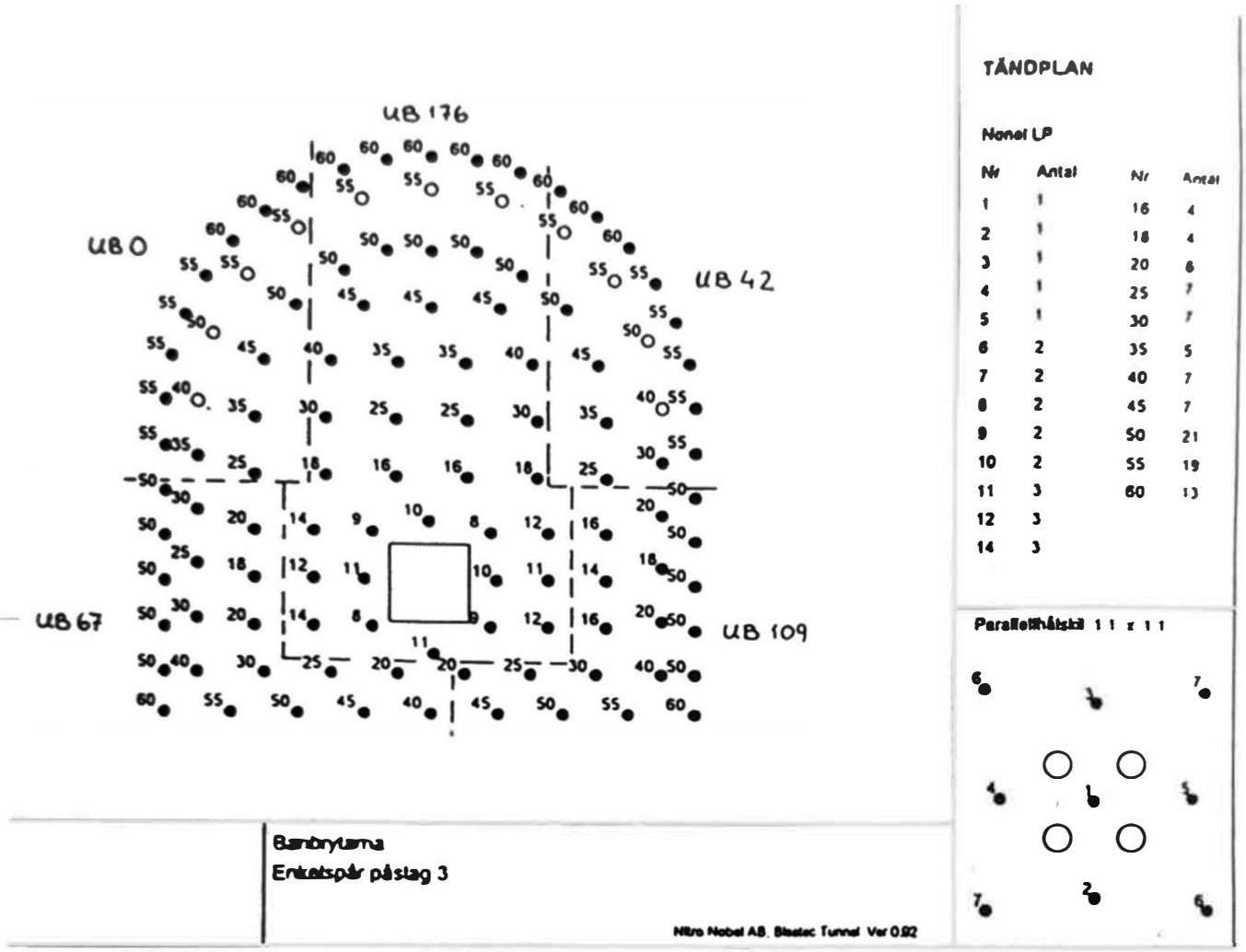

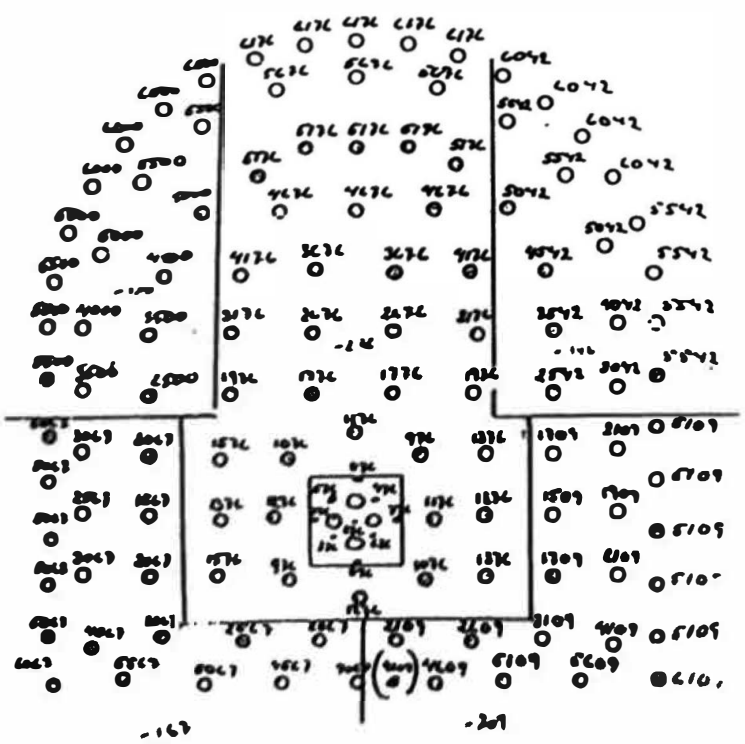

Fig. 11

Drill and ignition pattern from a single track tunnel

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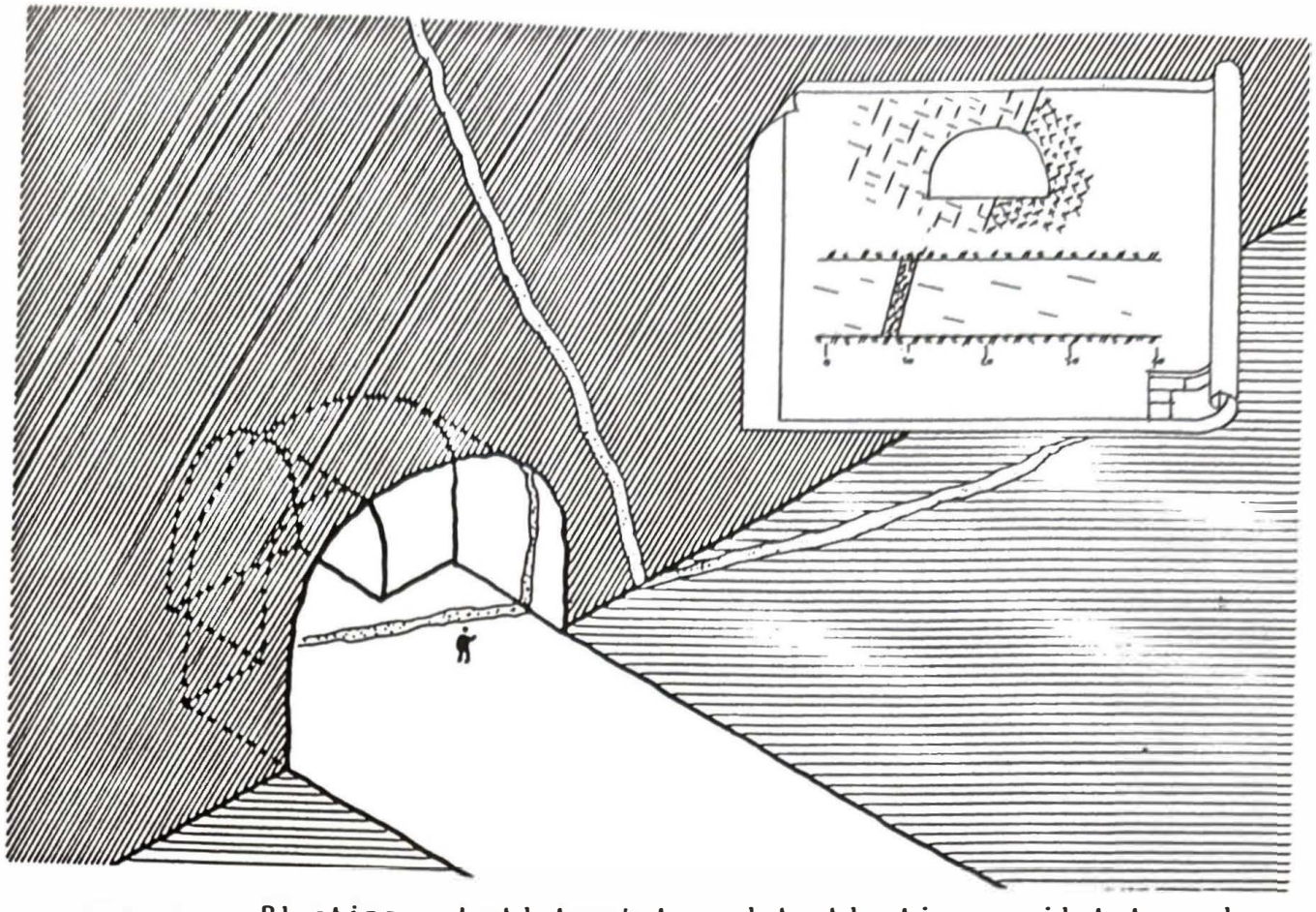

Fig. 12 Blasting a doubletrack tunnel by blasting a pilot tunnel first and then blast the stope

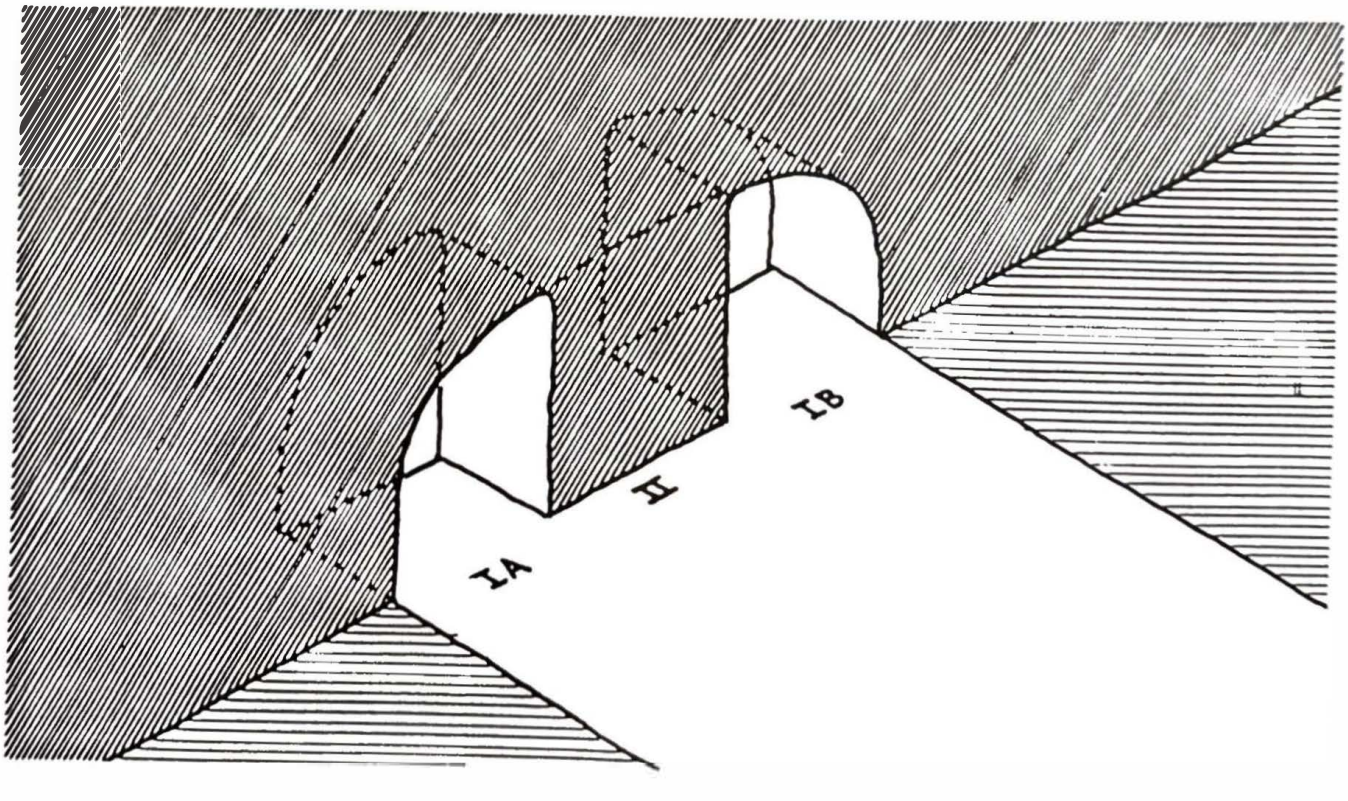

Fig. 13 Blasting for shuttle station in three sections