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ROCK SUPPORT OF THE L3 EXPERIMENTAL HALL COMPLEX*

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1 Introduction

The Large Electron Positron (LEP) Collider is the European Particle Physics Laboratory's (CERN) latest high energy machine and will no doubt remain the world's largest particle collider for some time to come, pending construction of the Superconducting Super Collider. The technical installations of the LEP accelerator-collider complex are housed in a ring-shaped tunnel, 27 kilometres long, situated between 50 and 170 metres below the surface. The tunnel passes through both French and Swiss territory, three quarters of it lying in the Pays de Gex and one quarter in the Canton of Geneva.

Electromagnets are aligned along the entire length of the LEP tunnel. A vacuum chamber, which is water-cooled and surrounded by lead shielding, is installed in the magnet gaps. The electrons pass through the vacuum chamber in an anti-clockwise direction while the positrons pass through in the opposite direction. The ring is not a perfect circle but consists of eight 2800-metre curved sections or arcs linked by eight straight sections. In the arcs, the particles are kept on course by 3392 bending magnets and the particle beams are focused by other magnets, namely 816 quadrupole and 504 sextupole magnets. Prior to each collision, the particles are accelerated as they pass through radiofrequency cavities, located in two diametrically opposite positions in the straight sections. The new particles produced by collisions are observed by large detectors mounted around the interaction points in the experimental halls. For the first construction phase, fully equipped experimental halls and detectors have been built at beam interaction Points 2, 4, 6, and 8 only. (Figure 1) The electrons and positrons, LEP's projectiles, are accelerated to just below the speed of light. In accordance with the theory of relativity, at this speed their mass is multiplied by some 200,000 times.

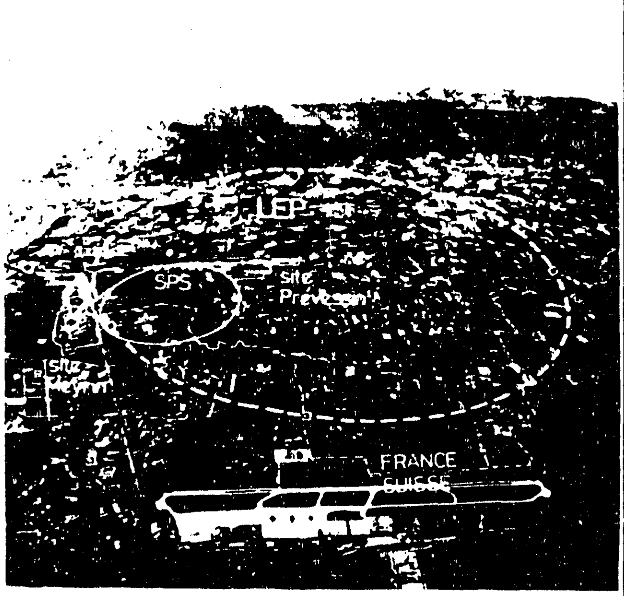

Fig. 1 - Aerial Photo of LEP

When accelerated, the electrons and positrons emit waves with a braking effect which increases with the curve of their trajectory, decreasing as the radius of curvature increases, but which almost entirely disappears when the particles are travelling in a straight line. Despite this drawback, a circular trajectory was chosen for LEP to increase the frequency of particle collisions. If two beams are travelling in opposite directions along a straight line energy losses will be lower. However particles will meet only once without any collisions necessarily occurring, whereas a ring allows the two particle bunches to pass repeatedly through the accelerating cavities and to meet very frequently, thereby increasing the likelihood of collisions.

The LEP Experimental Areas

The underground experimental halls contain large detectors arranged around the electron-positron collision points. As they are based on a variety of complementary technological systems and consist of a large number of modular units, these detectors are bulky and complex. The pure and applied physics content of such research is great, and physicists are expecting some very interesting experimentation in the rar of energies which will be obtainable at LEP.

The first four experiments chosen for LEP were selected on the basis of their physics potentials, technical feasibility and, as always, estimated costs. Each experiment has specific aims and the suite of experiments illustrates the ingenious and powerful array of techniques available to modern particle physics, many of which have gone on to provide important spinoffs in other applied fields.

L3 stands out from the other experiments in its physics aims: it is the largest of the four LEP detectors, and will identify and measure with great accuracy the momenta of the electrons, positrons, muons and light rays, resulting from the collisions. The muons will be measured in a barrel system with sixteen units, each 5.5 metres long and 2.2 metres wide.

In its structure, L3 differs from the other detectors because its magnet coil is near the perimeter of the detector. This ensures that all the experiment's concentric detection systems are enclosed within the magnetic field and that the required high tracking precision for muons will be achieved. Unlike the detectors in the other experiments, L3 cannot be moved out of the ring. The giant magnet is contained in an octagonal 'cylinder' 14 metres long and 15.8 metres high, and the whole detector weighs in at over 8500 tonnes. (Figure 2)

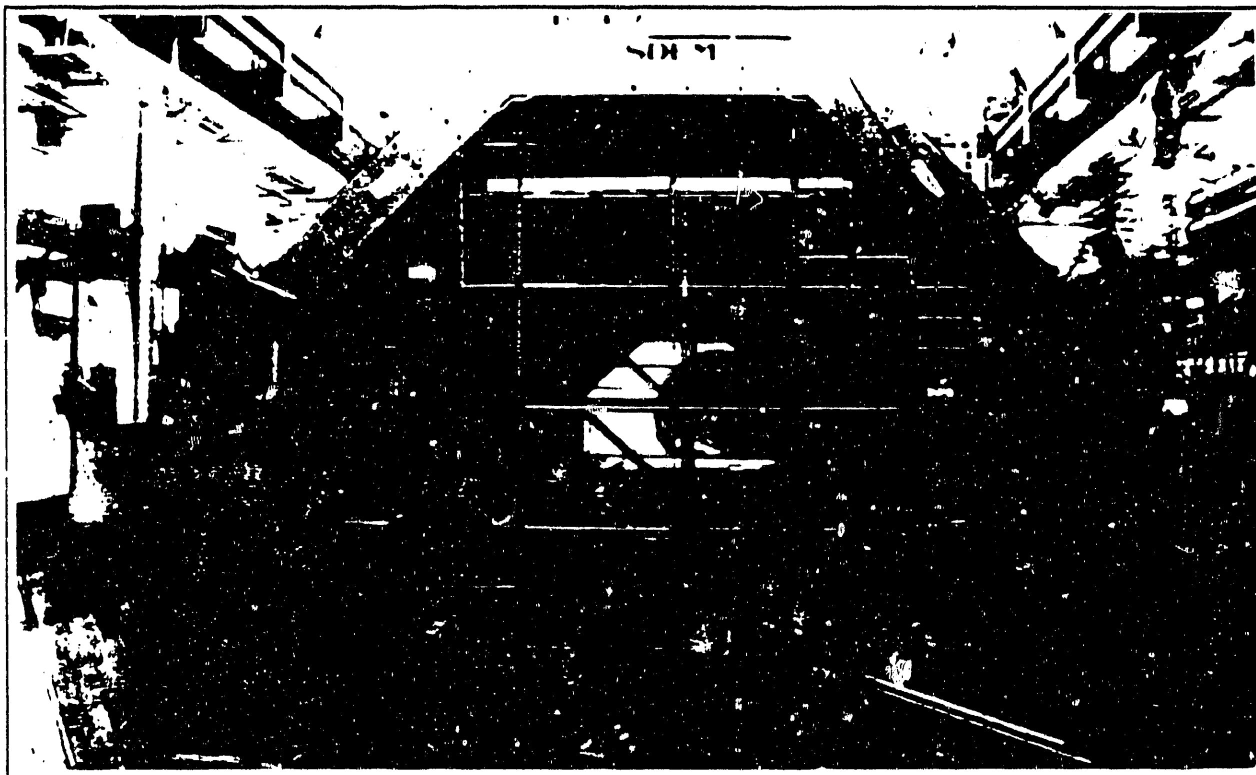

Fig. 2- Erection the L3 Octagonal Detector Structure

2 Geology

The excavation works for the LEP project are sited at depths of 50 to 170 metres below ground level and link up to an existing CERN tunnel complex, the Super Proton Synchrotron (SPS). Access to the LEP tunnel and experimental zones is provided by a set of twenty vertical shafts, varying in finished diameter from 5 to 23 metres. The main tunnel lies, for approximately nine-tenths of its length, in the bedrock strata of the Leman Basin and for one-tenth, in the mainly limestone strata of the Jura Mountains. In the Leman Basin, the "Molasse," which forms the bedrock in the region, is overlain by a series of Quaternary glacial moraine deposits.

The Quaternary moraines are neither consistent with depth nor horizon. The granulometry of the material varied from stones and gravels through to silts and clays with the occasional boulder present. (Figure 3). Deep and perched water tables exist locally around the site. At Point 2 the hall complex is sited at shallow depth below the Quaternary moraines (6 metres approximately) and a cover thickness of around 30 metres existed from ground level to hall crown.

The Molasse is a series of Tertiary perideltaic deposits consisting of alternating sandstone and marl bands of varying composition. The individual beds in the series of Molasse strata vary in thickness from 0.1 - 3.0 metres, a simplified classification and description are given below:

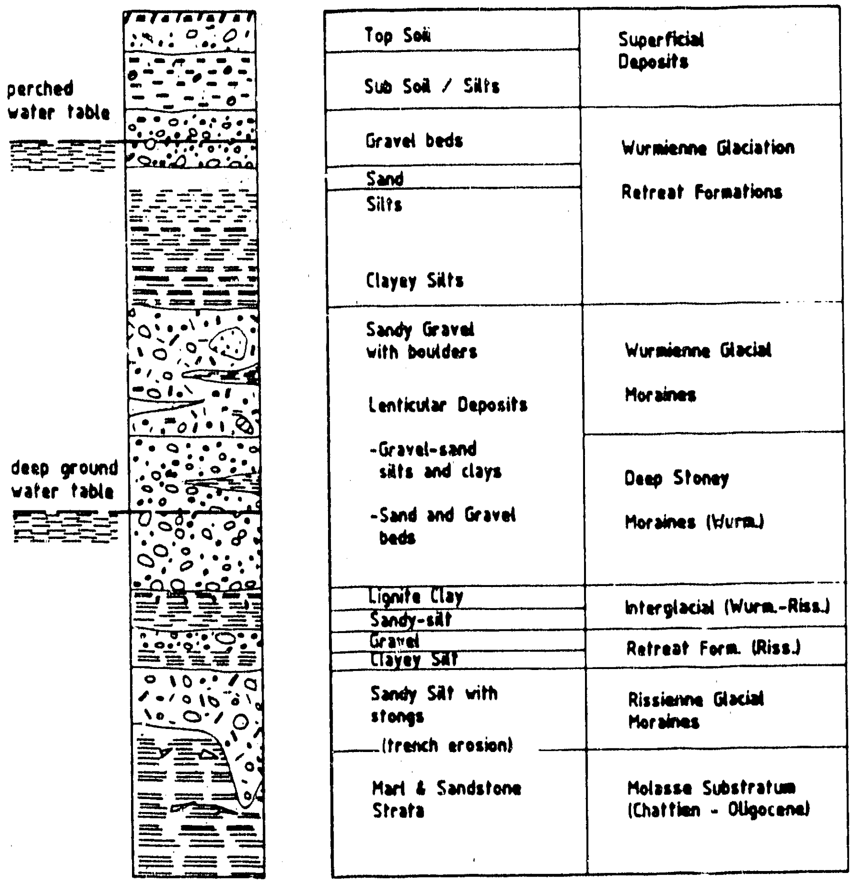

Fig. 3 - Typical Cross-Section through the Glacial Moraine Deposits of the Leman Bassin

I. marls; well consolidated strata containing a high fraction of argillaceous material, often including a proportion of montmorillonite. The marl beds possess a significant amount of oblique, closed fracturing, the surfaces of which are slickensided and striated. These beds presented a particular problem insomuch as the presence of the clay element renders the rock relatively sensitive to alteration. When left exposed to air or water, these strata are subject to either dessication or hydration, both of which can rapidly lead to a marked degradation in the mechanical properties of the rock.

II. intermediate facies, representing the marl/sandstone transition; relatively indurated strata containing a small amount of oblique fracturing.
III. coarse-grained, poorly cemented sandstones; containing a considerable degree of fracturing.
IV. fine-grained, well cemented sandstones, a set of compact beds containing a limited degree of fracturing.

The geotechnical characteristics of the Molasse "lithotypes" were obtained by a series of tests and measurements performed on borehole cores; the main characteristics are summarized in the table given in Figure 4.

The series of Molasse strata lying in the Leman Basin were subjected to folding activity during the Jurassic period. The associated earth movements of this era generated three folds, aligned with those of the Jura massif. The basin strata dip generally stays near horizontal. However, close to the Molasse/Jura unconformity, the strata dip increases to reach 15 to 20 degrees and the bed fracturing becomes more pronounced.[1] At Point 2 the strata are subhorizontal.

CHARACTERITICS	UNITS	MARLS	MARLS/SST.	SST. COARSE	SST. COMPT.	MOLASSE (PLAIN AVE.)
R.Q.D.	%	70-78	80-95	85-95	95-100	86.7
BULK DENSITY	kN/m3	24.5	25.4	23.9	26.1	25.3
PERMEABILITY	10^{-7} m/s	<0.1	<0.1	0.1	<0.1	<0.1
U.C.S.	MPa	3.3	9.4	9.6	22.3	12.75
U.T.S.	MPa	0.50	1.52	1.06	2.13	1.41
E (TANG.)	MPa	225	820	1260	2790	1443
OCCURENCE (GLOBAL AVE.)	%	20	30	10	40	--
AVE. BED THICKNESS	m	1.10	1.14	1.14	1.53	1.27

Fig. 4 - Summary Table of Molasse Geotechnical Characteristics

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Before the letting of the Civil Engineering contracts, the Molasse formation was investigated by borehole and an exploratory tunnel, which was located to intersect the Jura-Lemon Basin transition zone. Additional information, gathered during the excavation of other CERN tunnels sited in the same rock formation, notably that of the 8 kilometres long SPS collider, was also used to give an accurate assessment of rock mass conditions. To investigate the lithology, continuity and in-situ rock conditions at Point 2, three vertical boreholes were core-drilled into the bedrock.

Care was taken to limit the exposure time of the rock cores after extraction owing to the sensitivity of the marl strata to alteration. Equal care was necessary throughout the excavation and support phases of the cavern development to ensure that a minimum time elapsed between exposure of the rock profile and application of a protective shotcrete layer.

Results of the in-situ Lugeon tests carried out around the site showed the constituent strata to be of low permeability, only the poorly cemented, coarse-grained sandstones had a significant primary permeability. Secondary permeability existed in the superficial layers of the Molasse where the formation contained open fractures and was in contact with aquifer-bearing moraine deposits. Water inflows, at depth, within the Molasse structure were not encountered either during investigation or excavation at Point

2.

Excavation and Support Principals Adopted for Large Underground Structures

The same excavation and support techniques were adopted for all the hall and chamber structures.[2] Given the large dimensions of the openings, phased excavation of the rock was undertaken by roadheader with Front End Loader or Load Haul Dump spoil transport to sha base (Figure 5). Rock support was installed rapidly, once the opening profile had been formed. The temporary rock support consisted of 3 and 6 metres pattern rock bolting and a 10 to 20 centimetres thick reinforced shotcrete lining. The rock bolts were passive and fully bonded to the rock matrix by a cement based mortar. In most cases, the Molasse strata were sufficiently reinforced by the systematic installation of these New Austrian Tunneling support

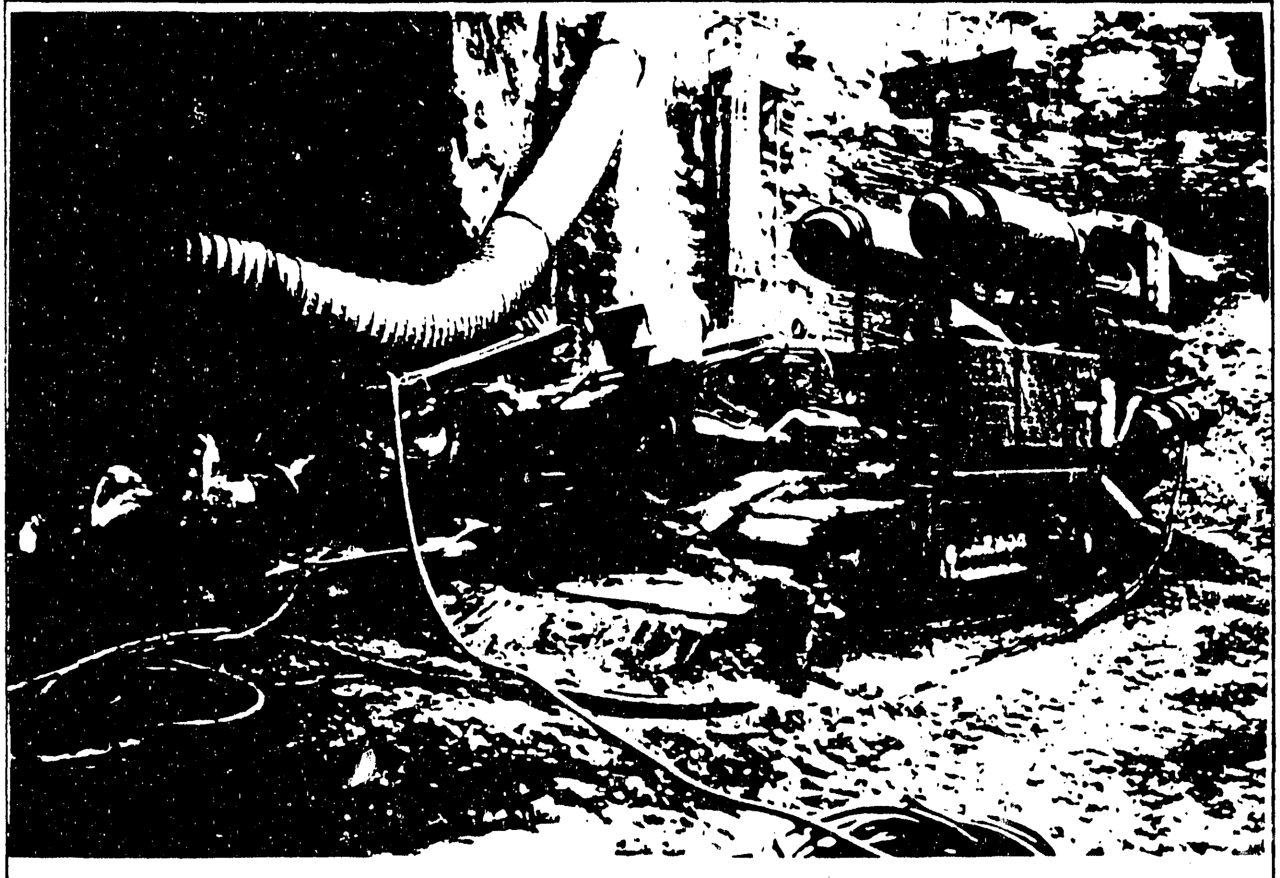

Fig. 5 - A Paurat E134 Roadheader at the Entrance to the Point 2 Experimetnal Hall

components. However, supplementary support was necessary in areas of overstressing as were found in the weaker marl beds, where plastic behavior was observed during excavation of the openings.

The support systems were designed to enable the rock mass, once reinforced, to play an active role in the support of the opening and ensure that any local yield deformations were contained. In the roof sections the bolting also ensured that the onset of bed separation was inhibited.

Final Lining

A second cast-in-situ concrete lining was added to each final hall and chamber structure after a standing period of 6 to 18 months once a medium-term convergence-confinement rock support equilibrium was obtained. The length of the standing period was normally governed by the work schedules of the associated underground structures.

In the main experimental halls (21.4 metres circular soffit diameter) the lining was poured in three sections sequentially; footwalls, soffit and final floor. For the smaller chambers (11 and 13 metres finished diameters) and machine halls, only soffit and floor pours were needed. For the main hall linings, the footwall and invert sections were designed to support and transfer potential floor swelling pressures to the arch structure by the formation of a "counter-arch" within the mass concrete structure.

The Point 2 Experimental Facilities

At Point 2 a unique layout was adopted for the Experimental and Machine Halls UX25 and US25, respectively. (Figure 6) UX25 has its longitudinal axis aligned with the LEP main tunnel and US25 is offset to the side behind a thin rock panel. At the three other Interaction Points at which experimental zones were constructed, the UX and US halls were excavated as one structure using a common axis, aligned at right

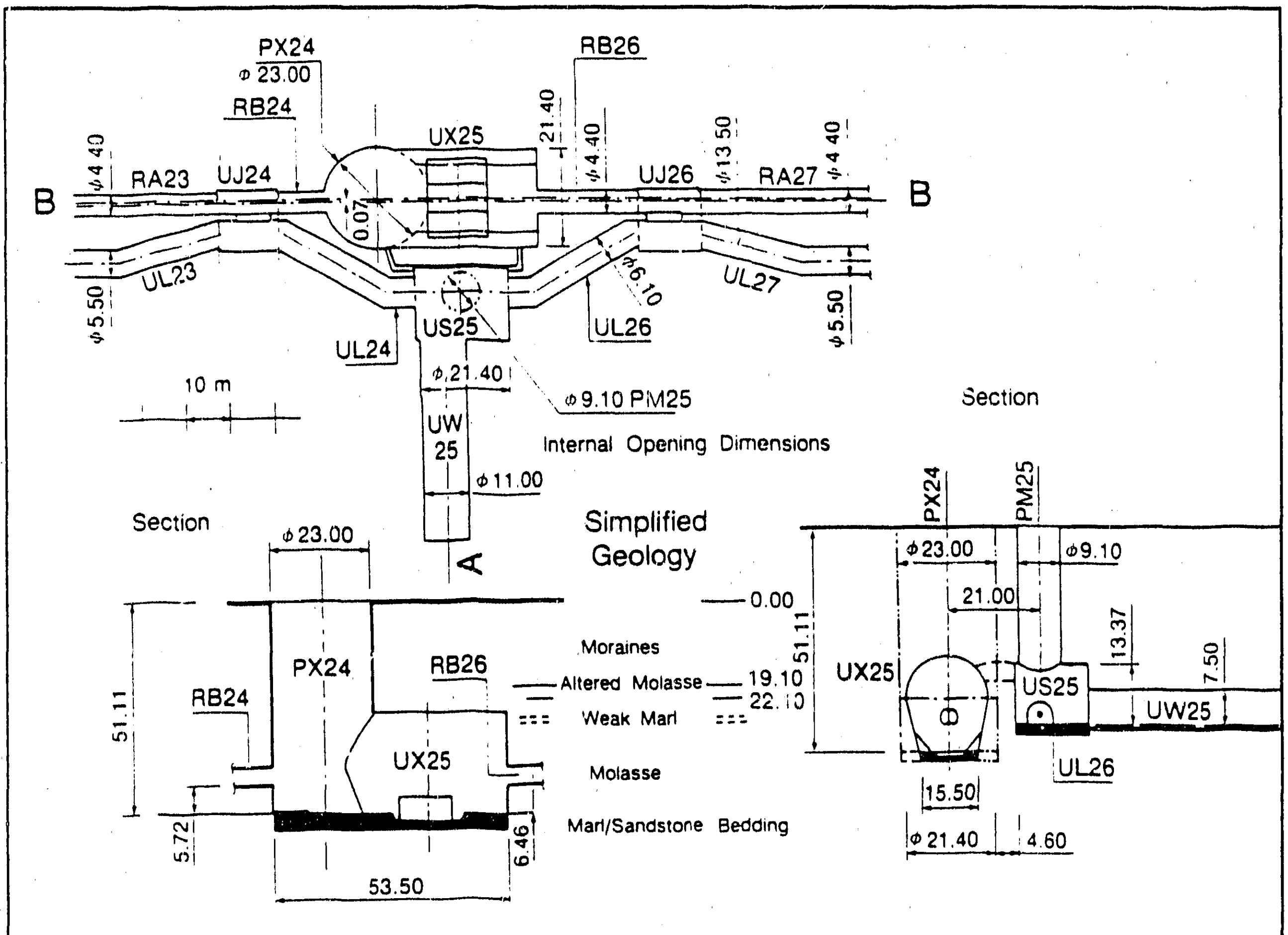

Fig. 6 - Simplified Layout of the Point 2 Underground Experimental Zone Structures

angles to the main tunnel. An identical arch profile was adopted for these halls.

The L3 experiment uses two circular vertical shafts for experimental and machine access, PX24 and PM25 respectively, which link-up into the UX and US halls. The PX shaft is the largest shaft to be excavated for the LEP project, having a finished diameter of 23 metres; a large opening was necessary to allow the large detector components to descend into their underground assembly area with a maximum degree of surface mounting having taken place. The PM shaft was sized to supply the main tunnel, in the vicinity of Point 2, with the power, control, cooling, ventilation, and access during services installation and operation of the machine. Secondary underground works required for machine operations include enlarged tunnel sections, liaison galleries, junction, and workshop chambers linked the principle machine and detector housings.

As can be seen from the plan of the L3 underground structures, for operational reasons the openings were very closely spaced, creating several highly stressed zones in the rock mass. This was particularly evident in the case of the rock panel which separates the UX and US halls; it was between 3 and 4 metres thick 10 metres high and over 20 metres long. The structure was weakened still further by two access labyrinths excavated in the panel; these openings later proved of interest allowing in-situ verification of the "structural well-being" of the panel. Thin ribs of rock material also existed between the UL24 liaison gallery and the PX24 shaft. A series of special temporary and permanent design measures were necessary to support these openings. The Point 2 works were further complicated by the relatively small amount of competent bedrock cover and consequent proximity of Quaternary glacial moraines, which contain an artesian aquifer at their base.

Construction of the L3 Underground Facilities

The excavation of the underground complex was undertaken simultaneously in the two shafts. Diaphragm walls were used for both shaft walls using contiguous reinforced panels of 1.02 and 0.62 metres thickness in the PX and PM shafts respectively. Pumpage of the artesian aquifers was maintained throughout the execution of the walling to improve wall stability during slurry trenching.

In the roof of the US halls, a tunnel was developed between the chambers for the length of the UX structure. Upon completion a reinforced concrete beam was cast-in-place. The function of the beam structure, placed at the shoulder of the UX25 openings above the UX-US panel, was to redistribute the ground loading more evenly about the main area of potential rock instability giving a net transfer of load away from the critical US section by the intermediary of the stiffer beam element.

After placement of the reinforced beam, excavation of both the UX and US halls was carried out using 4 to 5 metres high excavation passes. Rock support was added upon formation of the profile. In the case of the panel, a set of traversing lightly stressed Dywidag bolts and reinforced shotcrete layers were installed. At the junction between the UL and PX structures a 10 metre window was excavated and rock bolting/steel arching placed to support the shaft "overhang." This window served as a means of equipment transfer from the machine level to the experimental area during excavation; the shaft wall was later reinforced and reconstituted by a concrete support pillar.

Supplementary rock reinforcement was required during excavation of the UX cavern. The reinforcement was necessary to contain crown convergence during development of the second bench of the excavation. A yield zone appeared to have been created in a weak marl bed located in the crown of the opening. Fracture development was noted in the shaft and roof shotcrete linings, and the roof extensometer registered significant secondary convergence.

Reinforcement and modification of the rock support mechanisms was undertaken once temporary steel arch props had been installed to ensure safe working conditions in the area. To reduce the likelihood of hydrostatic pressure development from the artesian aquifer, the permeable moraines were again pumped, as they had been during the construction of the diaphragm wall panels. The water table was drawn-down and 9 and 12 metres long rock bolts were added to the original support pattern. The bolts were angled to ensure that they were fully anchored in the bedrock material and, hence, ensure no water path was established to the water bearing moraines.

Once the new rock bolting and an additional shotcrete layer had been placed, the steel arches were withdrawn and excavation of the main hall was recommenced. Pumpage of the artesian water table was continued until placement of the final lining to minimize vertical loading of the reinforced bedrock arch.

The marl layer which had created the disorders in the UX chamber also required additional reinforcement in the US and workshop (UW) sections. Outside the marl zone, excavation and support procedures followed those employed on the other experiment hall sites.

As a result of the levels of convergence obtained and the addition of a supplementary set of rock reinforcement measures in the roof, the finished structural alignment of the concreted chamber profile was lowered by 30 centimetres This was necessary to accommodate the 50 centimetres thick final concrete lining. Extensometers installed at Point 2 indicated that ground movements during the initial phases of excavation, were of the order of 10 to 20 centimetres. These convergence levels compare unfavorably with those measured elsewhere at the other three experimental facility complexes.[3] At the deepest hall, over 130 m below ground level and with nearly 100 m of rock cover, convergence measures recorded during excavation were of the order of 4 to 5 centimetres, well within boundary element model predictions. Hence, there was no conflict with final lining thickness requirements.

The final lining was designed to resist any long-term deformation in the rock mass. The lining incorporated steel arching, on which the two forty tonne gantry cranes were mounted, and supported a waterproofing and drainage complex.[4]

The more rigid lining ensures long-term stability of the structure and provides a satisfactory laboratory environment. The machine and detector equipment needs to be securely founded; even millimetric displacements would provoke shutdown and the realignment of equipment, a costly business given that over a thousand individuals are involved in the running of the machine and its associated experiments.

In the flat wall end of the main halls, where stability was less critical to machine and detector operations, a gap of 20 centimeters was left and a "cosmetic" wall was slip-formed independently, with permanent rock support given by rock bolts and shotcrete. This allows long-term deformation of the wall structure within the 20 centimetres void while producing no internal disruption.

Prior to placing the footwall and soffit linings, a drainage and waterproofing complex was installed against the shotcrete surface. This "umbrella" system ensures that any water infiltration through the rock matrix or behind the shaft lining, from the overlying moraine levels, is captured and channelled to the floor drainage channels and eliminates hydraulic loading of the internal lining. (Figure 7)

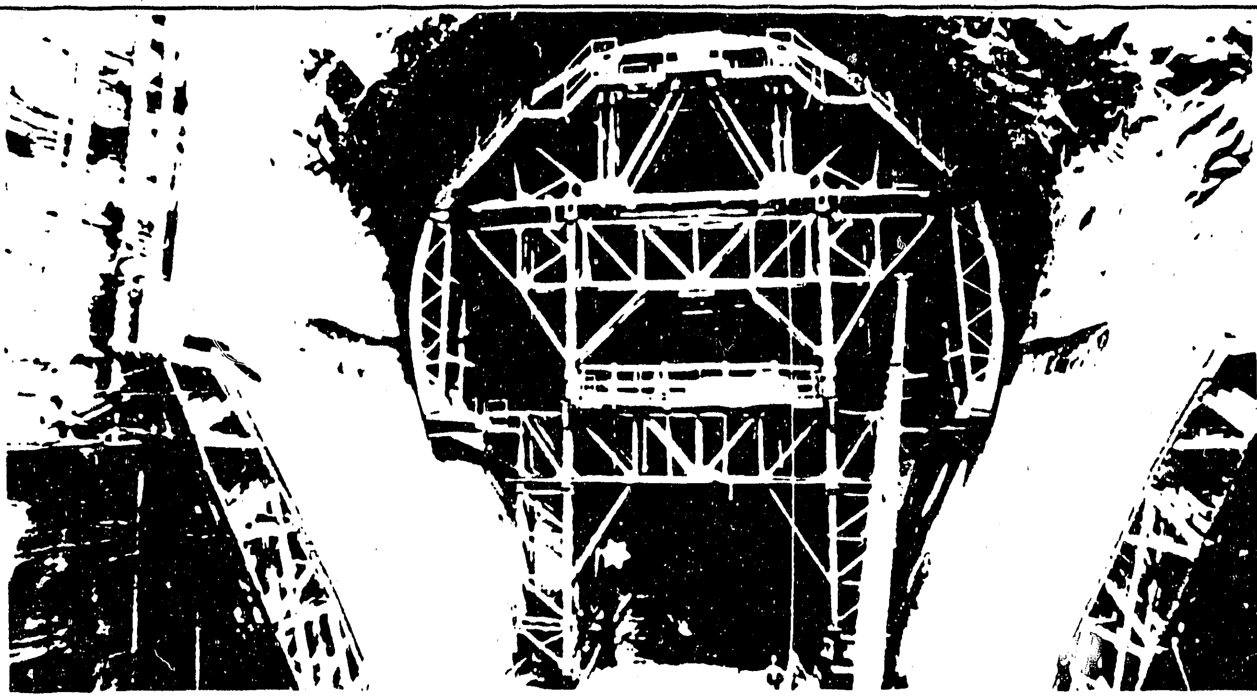

Fig. 7 - PLacement of Concrete Framework for the U x 24 Hall Arch Pour

Conclusions

The methods of excavation and support selected for the LEP works proved most effective. In particular, the excavation of the halls and chambers in discrete passes, from the roof down, and their temporary support by patterned fully bonded rock bolts and shotcrete ensured that mass deformations were contained.

When working in soft rock materials where discontinuity, elastic and possibly plastic deformations may each play an important role in the overall rock structure stability, it is of paramount importance to systematically monitor the behavior of the rock in-situ. The use of instrumentation to indicate location, direction, levels, and rate of movement is essential to ensure that a safe, efficient and economical mining operation can be undertaken, and that any remedial action will be taken at the appropriate time.

The use of the New Austrian Tunneling support mechanisms allowed the engineer greater flexibility in handling local reinforcement of the rock structure if superficial or relatively deep-seated instability was encountered. However, in the case where second linings are to be accommodated and flexible support mechanisms used, care should be taken to foresee over-excavation in weaker zones to allow for larger displacements prior to the attainment of confinement-convergence equilibria.

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