TWO NEW CAVERNS FOR LHC EXPERIMENTS : ATLAS AND CMS

H. Rammer
ST Division – Civil Engineering Group (ST/CE)
CERN, Geneva, Switzerland

Abstract
The LHC will utilize much of the existing infrastructure already constructed for the LEP. However, to house the new ATLAS and CMS detectors, two huge cavern complexes are required at Point 1 and Point 5 on the LEP. The civil engineering design criteria for the two caverns are presented. Attention is directed to the decisive constraints for the design, such as adverse geological ground conditions, the three-dimensional complexity of the shafts, caverns and tunnels, and the existing LEP structures in the vicinity of the new works which remain operational for the first two years of the project. The paper will demonstrate the different basic requirements of the new underground structures at Point 1 and Point 5. The comparison of the two projects from a civil engineering point of view will aim at explaining why different technical solutions have been adopted for the design and construction of these works.

1. INTRODUCTION

The civil engineering works for the LHC Project are divided into three main packages plus one lot for one of the new injection tunnels. Package 01 consists of all the new underground and surface structures to be constructed on Swiss territory at Point 1. The new structures include two large caverns perpendicular to each other, two shafts, associated tunnels and chambers, and several new surface buildings. Package 02 will be constructed on French territory at Point 5 and consists of two parallel caverns in close proximity to each other, two shafts, several tunnels and galleries, and a range of new surface buildings. Package 03 consists of several kilometers of new tunnels, small caverns and shafts, as well as several new steel and concrete surface buildings, all distributed at various sites around the LEP tunnel.

The design and construction supervision of these new works was awarded in separate packages, each one to a different multinational joint venture of engineering companies. Similarly, the contracts to construct the new works are to be awarded in these packages to different international contracting consortia.

Package 01 is currently being designed by a joint venture between Electricité de France (France) and Knight Piésold (United Kingdom). Package 02 was awarded to a joint venture of Gibb (United Kingdom), SGI (Switzerland) and Geoconsult (Austria), and Package 03 to a joint venture of Brown & Root (United Kingdom) and Intecsa (Spain).

The construction contracts will be awarded to the following three consortia: Package 01 to Teerag Asdag (Austria), Baresel (Germany) and Locher (Switzerland); Package 02 to the Spanish/ Italian joint venture comprising Dragados and Seli; and Package 03 to the Anglo/French consortium of Taylor Woodrow, Amec and Spie Batignolles.

2. DESIGN CRITERIA

2.1 Geology

The CERN site is located in the Geneva Basin, between the Alps to the south-east and the Jura mountains to the north-west. The Basin is infilled by sedimentary deposits, collectively called molasse. These deposits comprise a complex, alternating sequence of almost horizontally bedded sandstones and marls, with a range of composite marly sandstones and sandy marls.

The molasse is overlain by moraines from the glacial periods of Riss and Wurm. The deposits of the Rissien age are mainly of gravel and sands, whereas the overlying deposit of the Wurmien age consists of silty and clayey gravel with many cobbles and a few boulders. The depth of the moraine varies, with less than 10 m at Point 1 and about 50 m at Point 5.

2.2 Site Investigations

In the years 1981 and 1982, prior to the construction of the LEP, a major geotechnical investigation was carried out. Numerous boreholes were drilled and tested along the proposed tunnel alignment, including a number of boreholes both at Point 1 and Point 5. Rock samples were recovered for subsequent laboratory testing and a certain amount of *in situ* testing was carried out.

An extensive site investigation was undertaken for the LHC project between 1995 and 1997, consisting of 29 boreholes and a substantial quantity of *in situ* and laboratory test work. A total of 2800 linear meters of core drillings was carried out, 1865 m of it in molasse rock [1]. The purpose of this investigation was to achieve the following main objectives. Firstly, to determine the distribution of the various lithologies within the moraine and the molasse; secondly, to determine geotechnical properties; thirdly, to investigate the hydrogeology of the site and, lastly, to investigate the *in situ* stress regime within the molasse.

2.2.1 Geotechnical Model at Point 1

Based on the data from the most representative boreholes, a detailed geological model of the ground at Point 1 was derived. The sequence of the various rock types was described in detail, and then simplified into a series of bands with generally similar properties. For modelling purposes, these bands have been further simplified into three basic rock mass units.

The upper unit consists predominantly of sandstones with some intermediate layers of marls. This unit extends from the base of the moraine, at depths between 4 and 10 m, to depths down to 50 m. The middle unit extends to depths of more than 80 m and is the most variable of the three units. It consists of about 40% sandstones, 45% marls and 15% transitional rock types. The lower unit consists predominantly of marls (60 to 70%), with 25% sandstones and a minor proportion of transitional rock types [2].

Strength and deformation parameters, derived from the various laboratory tests, have been allocated to each type of rock. The relative proportion of each rock type within each rock mass unit was used to derive design parameter values for each rock mass unit. Separate bands of the weaker marls were included in the geotechnical model, as they are of importance for the overall behaviour of the rock mass and the stability of the underground structures.

2.2.2 Geotechnical Model at Point 5

To build up a meaningful geotechnical model of the Point 5 site, the lithological sequences shown on the borehole logs have been simplified and rock type units of similar character have been defined. These geotechnical units, such as sandy marls, marly sandstones, etc., have been grouped together and correlated across the site. Then, geotechnical parameters have been assigned to these groups. Particularly weak units, such as ‘marl grumeleuse’, have been included as individual bands.

Thus, the molasse rock at Point 5 is represented in the geotechnical model as an alternating sequence of marly sandstones and marls with subordinate sandy marls, varying in thickness between approximately 1 and 10 m. These predominant composite units are interbedded by several calcareous horizons of thicknesses of normally around 0.5 m, and layers of sandstones with a thickness of up to 5 m. The bedding has a general dip of approximately 5° towards the south-west [3].

The moraine at Point 5 goes to depths between 43 m and 50 m and consists of very dense silty, sandy and clayey gravel. The moraine is known to be water bearing, and two separate aquifers have been identified at Point 5. The two aquifers vary in thickness over the site from 10 m to 22 m and are separated by a layer of silty-clayey gravel of thicknesses between 5 m and 20 m.

2.3 Principal Works

The principal underground works at Point 1 consist of the two new shafts PX14 and PX16, 18.0 m and 12.6 m in diameter, providing access to the new experimental cavern UX15. This main cavern with internal dimensions of 30 m in width and 35 m in height will be built with its axis parallel to the LEP/LHC beam tunnel and will house the ATLAS detector. The cavern floor will be situated at a level of approximately 92 m below ground, thus leaving more than 50 m of rock cover over the cavern crown. Perpendicular to the UX15 cavern, the large service cavern USA15 will be built. This cavern with a spring line diameter of 20 m and a length of 62 m will be connected to the PX15 shaft. PX15, an existing unlined shaft which was used during the construction of the LEP, will be strengthened and lined and will provide the main personnel access to the new underground structures. Various smaller access and services tunnels will link the UX15 and the USA15 caverns. Some chambers will enlarge the existing beam tunnel to provide the required space for the transport of the LHC magnets and to house auxiliary services.

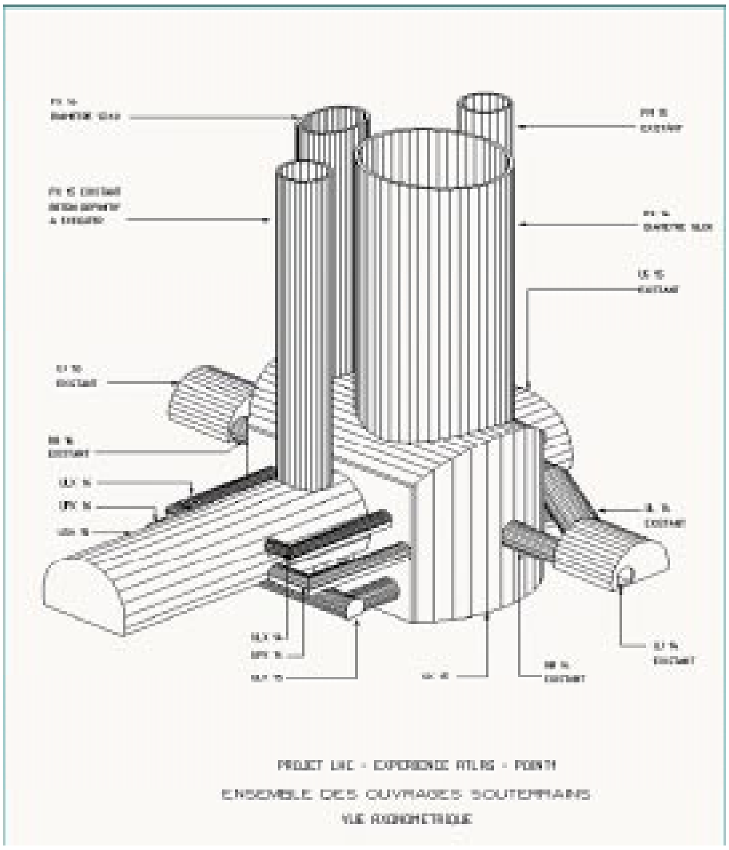

Fig. 1 Underground structures at Point 1.

The new underground structures at Point 1 will be built around and into the existing LEP facilities. They consist of the PM15 service shaft, providing access to the US15 service cavern, and of two galleries connecting the US15 to two junction chambers on the LEP beam tunnel.

The underground works at Point 5 consist of two new caverns, two new shafts of 20.4 m and 12.0 m internal diameter, a number of smaller connection and services galleries, and tunnel enlargements on the existing LEP tunnel. The new experimental cavern UX55 (26.5 m wide and 24.0 m high) and the service cavern US55 (18.0 m wide and 11.5 m high) are parallel and in close proximity to each other. The rock cover to the main cavern is only around 20 m with an overburden of 50 m moraine above.

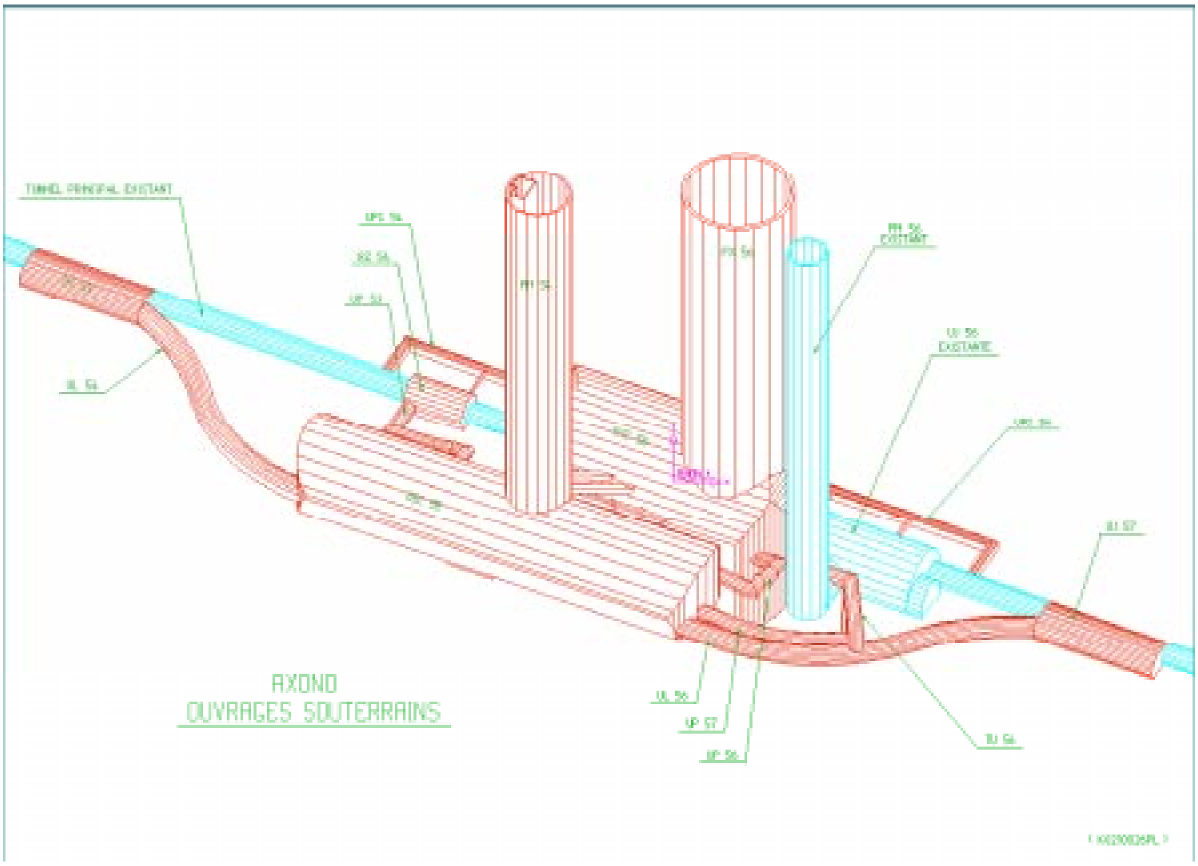

Fig. 2 Underground structures at Point 5.

Similar to the arrangement at Point 1, the new underground structures at Point 5 will be built adjacent to the existing ones. The underground LEP facilities at Point 5 comprise an access shaft, a chamber and the beam tunnel itself.

2.4 Requirements

2.4.1 Physical Constraints

The following CERN operational and design requirements from the scientific equipment force major constraints on the layout of the underground structures.

1) The size of the detectors to be installed in the experimental caverns.
2) The large diameter access shafts required to lower pieces of equipment into the caverns.
3) The need to construct the services caverns as close to the experimental areas as possible.
4) The integration of the new works into the existing structures.

More constraints are imposed on the design of the new works by the following issues:

- The presence of the existing structures which remain operational for the first two years of the construction period;
- The construction of the new works within a rock mass of horizontally bedded rock, including weak strata and rock types sensitive to swelling and creep;
- The requirement for a watertight final lining;

- The requirement for a watertight cut-off at the base of the moraine to prevent water migration along the shaft linings into the molasse;
- The limited precedent for caverns of that size in soft rock.

The particularities in that respect are at Point 1:

- The three-dimensional complexity of the shafts, caverns and tunnels;
- The main cavern which is adjacent to and intersected by the new auxiliary cavern and the existing service cavern; this limits the shape that can be adopted for the cavern;
- The high vertical cavern side walls which are not the most advantageous in that type of ground, in particular with respect to the high horizontal ground stress.

Particularities at Point 5:

- The shafts to be sunk through 50 m of water bearing moraine into the molasse;
- The proximity of the two parallel caverns giving a combined span of more than 50 m;
- The low rock cover of around 20 m to the overlying moraine strata.

2.4.2 Programme Constraints

To meet the tight overall LHC project schedule, as much of the construction work as possible will need to be completed before the final LEP shutdown. However, major portions of the works can only be executed thereafter, when all the LEP equipment will have been dismantled and removed from the tunnel. These constraints, together with the expected movements of the existing tunnels caused by the excavation of the new openings, need to be taken into account for the determination of the optimal construction sequence.

3. NUMERICAL ANALYSIS

Before starting any stability analysis of underground structures, it is necessary to develop a meaningful geotechnical ground model, as outlined in Section 2.2, and to define which behaviour law and which failure criteria best match the prevailing ground conditions. In addition, the rock support system must be defined, and all the other design criteria described above must be formulated to be incorporated into the numerical model.

The main objectives of the analysis of the underground structures are:

- to give a comprehensive understanding of the rock mass behaviour,
- to dimension and adapt the primary rock support and the final inner lining,
- to optimize the excavation sequence.

An overview of the civil engineering design work performed for the ATLAS cavern complex at Point 1 is given in [4]. That paper presents the design methodology applied for the underground design, including a description of the software used for the numerical analysis, an outline of the principal results of the computations, and the conclusions drawn from those results for the structural design and the construction methods.

Similarly, a series of approaches and software systems have been adopted for the analysis of the CMS caverns at Point 5. Initially, the overall stress development after excavation was studied with ‘Examine 3-D’, a boundary element programme, taking into consideration the three-dimensional complexity of the works. A typical two-dimensional cross-section across the two parallel caverns was then analyzed with UDEC. This code allowed a very detailed modelling of the rock mass and the study of a wide range of load cases, including long-term load cases due to swelling and creep.

Finally, the whole underground complex was again analyzed in 3-D with ‘BEFE’, a ‘Boundary Element - Finite Element’ programme, which modelled the rock mass with boundary elements and the concrete linings with a more detailed finite element mesh.

4. CONSTRUCTION METHODS

The nature of the rock that will be encountered around the new underground openings, as well as the aim to limit construction costs, result in a preference for construction methods that will make best use of the self-supporting capability of the rock. Construction techniques permitting controlled convergence of the ground during excavation will decrease the stresses in the final concrete linings. Such techniques require the systematic installation of primary rock support as quickly as possible after excavation, consisting of shotcrete and rock bolts. The permanent support for the underground excavations will be installed thereafter, generally comprising a waterproof membrane and the structural concrete linings.

However, to accommodate the particular demands outlined above, the following special construction methods will be adopted for the execution of specific parts of the underground works.

4.1 Shafts

The shafts at Point 5 are to be sunk through 50 m of water bearing moraine into the molasse. The prevailing ground materials, the scale and the proximity of the three shafts, together with the requirement for a watertight cut-off between the moraine and the molasse, represent a challenging situation. From a number of possible construction methods, ground freezing of the moraine is considered to be the most appropriate. In addition, a primary concrete lining will be constructed during excavation, followed by the installation of a waterproof membrane and then slipforming of the final concrete lining. A grout curtain will be injected into the ground to achieve the water stop.

4.2 Caverns

The excavation works will cause ground movements around the new openings. As closer the excavation will approach the existing structures, as higher will be their displacements. However, the existing structures must remain fully functional during the operational period of the LEP and the SPS. The accelerators can tolerate only very small displacements during operation and there is only limited capability for adjustment of the alignment of the magnets. A compromise must be found between the acceptable movements of the existing structures and the amount of construction activity in the vicinity of those ones.

This resulted in the following principal construction sequence adopted for the execution of the works at Point 1:

- Excavation of the PX14 and PX16 shafts before excavation of the UX15 vault.
- Excavation of the UX15 cavern vault, concreting and anchoring of the crane beams, followed by the construction of the concrete vault; everything before LEP shutdown.
- In parallel but independently from UX15: excavation of USA15 cavern vault, excavation of the benches, then installation of the complete concrete lining; to be completed before LEP shutdown.
- After LEP shutdown: excavation of the UX15 benches, then concreting of the invert and walls; in parallel, construction of ancillary tunnels and chambers.

The main feature with regard to special construction techniques for the caverns at Point 5 is that the rock between the two caverns will be replaced by a concrete pillar. Due to the high stresses induced from the excavation, it is necessary to increase the thickness of the pillar from 3 m to 7 m by moving the caverns apart. In addition, a concrete invert arch will be constructed under the floor of the experimental cavern. This will give a vertical support against the swelling pressure from the rock below the invert and a horizontal support for the concrete pillar.

5. CONCLUSION

The realization of the LHC project will occupy the major resources at CERN for the next couple of years. Although making up only about 10% of the total project value, the civil engineering part in its own represents an outstanding challenge for designers, contractors and the client. The new underground structures at both Points 1 and 5 are complex and of unprecedented size in that type of ground conditions. The presence of the existing structures in close proximity to the new ones, and the necessity to keep the existing facilities operational for the first two years of the project, posed particular problems not only to the design and the planning, but will also constitute an important factor for the proper execution of the works.

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