OPTIMISATION OF THE DESIGN OF THE FUTURE CIRCULAR COLLIDER FROM A CIVIL ENGINEERING PERSPECTIVE

J. Stanyard, V. Mertens, J. Osborne, CERN, Switzerland
Y. Loo, C. Sturzaker, M. Sykes, ARUP, UK

Abstract

This paper describes the role of civil engineering in the optimisation of the design of CERN's Future Circular Collider (FCC). The civil engineering team at CERN have employed a bespoke, interactive, geological tool to consider the suitability of multiple layout options for the FCC, situated in the Geneva Basin, in particular quasi-circular options with circumferences in the order of 100 km. The tool has been used to provide feedback on potential lattice designs that are assessed based on criteria such as geological risk, shaft depth and the environmental sensitivities of access and experimental sites. This paper presents the process and some results of the impact of civil engineering on the design of the FCC, in particular on the layout, location, and structural requirements, and also how the optimised design has been used as the basis for a cost and schedule study.

INTRODUCTION

The feasibility of a Future Circular Collider (FCC) at CERN as a successor to the Large Hadron Collider (LHC) has been under investigation since the kick-off meeting hosted in Geneva in 2014. Subsequently, a variety of options have been considered ranging from 80-100 km circular colliders to less conventional, racetrack shaped designs. The focus of the study is now on a quasi-circular layout with a circumference of approximately 100 km, incorporating the infrastructure to house two different machines in different phases (hadron and electron colliders).

It is estimated that for the LHC, civil engineering accounted for approximately one third of the consolidated cost [1], hence there is significant emphasis on civil engineering at this early stage of the FCC study. Various lattice designs have been assessed from a civil engineering perspective, using an interactive geological tunnel optimisation tool (TOT), initially to verify feasibility, and then to locate the best position in the Geneva basin for each layout design.

This paper describes the method by which potential layouts are assessed and how the geological and surface implications have affected the design.

LAYOUT ASSESSMENT METHOD

A range of lattice designs for the FCC have been produced, each with small variations in the lengths of the straight sections and arcs. These files are uploaded onto TOT and assessed by CERN's civil engineers. Within the tool, the machine shape can be moved laterally and rotated in the x,y plane, and the depth at the centre of the shape can be adjusted in the z direction. The angle of the slope of the tunnel is also adjustable; it is necessary for the tunnel to be positioned with a small gradient in order for a gravity drainage system to be utilised.

The position of the tunnel layouts are adjusted into an optimal position and evaluated on the criteria in the following sections.

Geology along the Tunnel Alignment

The initial assessment of the tunnel alignment is based on the geology along the length of the tunnel. Figure 1 shows the graphical output from TOT illustrating the geological conditions along the profile of an example layout. It is the aim of the civil engineers to maintain the tunnel in the Leman Basin sedimentary rock, known as molasse, for as much of the length as possible. This strategy has been implemented based on previous experience at CERN, where the molasse has provided favourable conditions for tunnelling with a Tunnel Boring Machine (TBM) [2]; in comparison, significant issues with water ingress and damage to the tunnel due to a build-up of water pressure have arisen in the sectors of the LEP tunnel excavated in the Jura limestone. Tunnelling in the fluvio-glacial deposits, known as moraines, is also considered a risk, especially water bearing moraines under the lake, as the conditions are soft and inconsistent. However, it is possible to excavate in the soft ground using a multi-mode TBM with an earth or slurry pressured system [3].

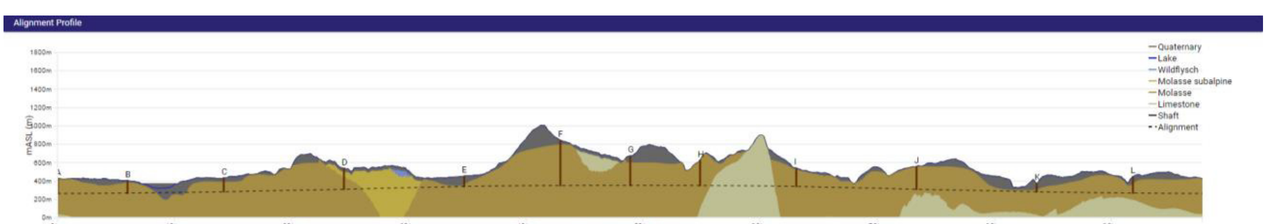

Figure 1: Example graphical output from TOT showing the geological profile.

Overburden

During excavation there is a risk of rock squeezing at the face of the excavation, leading to the TBM potentially becoming immobilized [4], which would have significant repercussions on the schedule; this risk is exacerbated by a large overburden. It has therefore been a strategy to try and limit the depth of the overburden in order to mitigate this risk, the result of this is that wherever possible the tunnel has been kept out of the Pre-Alps and Vuache regions, where the depth of ground cover becomes excessive.

Shaft Depth

Shaft depth is also a major consideration when locating the machine tunnel; it is important to consider both total shaft depth and individual cases of very deep shafts. There are significant cost and schedule benefits of reducing the total shaft depth, as vertical construction is notably more expensive and time consuming than the horizontal construction of the tunnel. Reducing the depth of the shafts also has the secondary benefit of reducing lengths of the services required for the operation of the accelerator. It is also intended to avoid having any individual very deep shafts, as this introduces additional construction and schedule constraints.

Surface Locations

As the feasibility study progresses, further consideration is being given to the location of the surface sites. TOT is able to automatically identify clashes with buildings and protected areas, but there are further constraints to be considered in addition, such as access and gradient of the particular site.

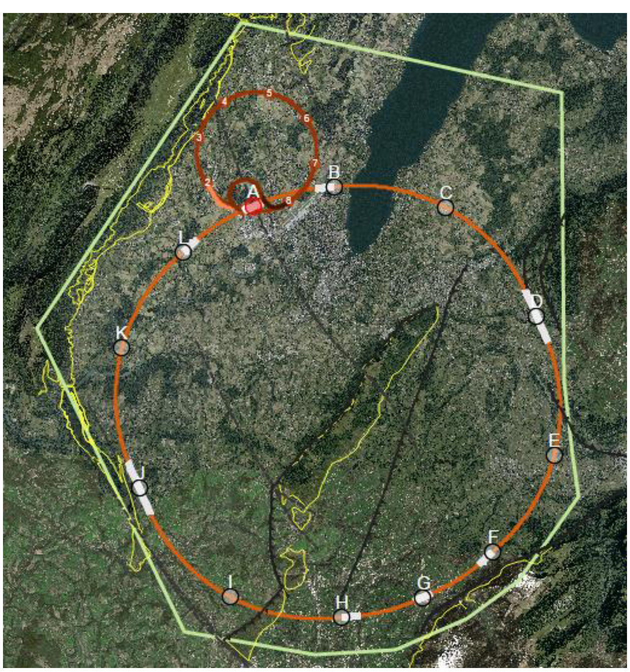

Figure 2: Example position of 97.75 km layout.

RESULTS OF THE LAYOUT ASSESSMENT

These are a sample of the key parameters that are considered when evaluating potential machine layouts and positions. This analysis is undertaken by CERN's civil engineers using a combination of quantitative and qualitative methods. Figure 2 shows a proposed position of a layout following assessment based on the discussed criteria.

The results from the assessment of the different layout options indicate that, even when the total circumferences of the lattice files are the same, the different configurations of lengths of straight sections and arc lengths create significant differences in terms of risk and feasibility. This is due to the 100 km quasi-circular design fitting tightly within the natural boundaries of the Jura Mountains to the north-west, the Vuache Mountain to the south-west and the Pre-Alps to the south-east and east, meaning small differences between layout designs can easily lead to notable differences in the output. The favoured layouts avoid the Jura and Pre-alps limestone whilst also avoiding exceptionally deep shafts at Points H, G and F, however it has proved difficult to simultaneously fulfil these criteria. The surface site locations of point A and B have also proven to be critical, as B is in close proximity of Lac Leman and in certain siting solutions it is possible to place Point A on CERN land close to the Meyrin site; this is an attractive option for the study as Point A will house one of the main experiments. It is likely that some shafts will be shifted along the length of the tunnel from their original positions to avoid difficult surface locations such as protected water sources and built-up areas; it has been deemed acceptable for the shafts located at points that do not house experiments or the beam dumps to be adjustable.

There have been extensive studies regarding the depth at which the tunnel passes below Lac Leman. An early strategy involved avoiding the fluvial deposits, known as moraines, as these soft and inconsistent conditions are considered a risk. However, this strategy had a large negative influence on the total shaft depth as this was the critical feature defining the depth of the tunnel. Positions are now under consideration that include the tunnel passing through the moraines under the lake.

The assessment process has indicated that it is very difficult to position the tunnel in such a way that avoids having at least one undesirably deep shaft; inclined access tunnels are therefore being considered as an alternative or complementary structure. Adding inclined tunnels could facilitate an accelerated programme for the construction of the tunnel as the additional access points can potentially bisect the longer arc lengths to allow two construction fronts.

DESIGN AND PLANNING DEVELOPMENT

In parallel with the layout assessment, the study of the construction methods and design of the works has evolved.

ISBN 978-3-95450-182-3

As discussed in the layout evaluation, TBMs are the preferred construction method for the molasse, whilst traditional drill and blast excavation is the presumed excavation method for the sections including limestone. The concept for the lining is still under consideration, however it is likely there will be a combination of single and double lined sections in the tunnel, depending on the local conditions. It is also anticipated there will also be some structures excavated using roadheaders or hydraulic hammers; these include the 16 large caverns required to house the experiments and other machine services, and also the numerous small alcoves located each 1.5 km along the tunnel for electrical equipment.

As part of the design development, some key features of the infrastructure have been relocated to profit from beneficial geological and surface conditions. Most notably, the secondary experimental points have been moved from points F and H to points L and B. Shafts L and B are significantly shallower than those on the southern side of the ring, during construction, this allows spoil from these large caverns to be removed faster, and for installation, the reduced shaft depth offers significant savings in terms of lengths of services. This layout has the additional advantage that the two experiments in L and B will be close to the CERN campus.

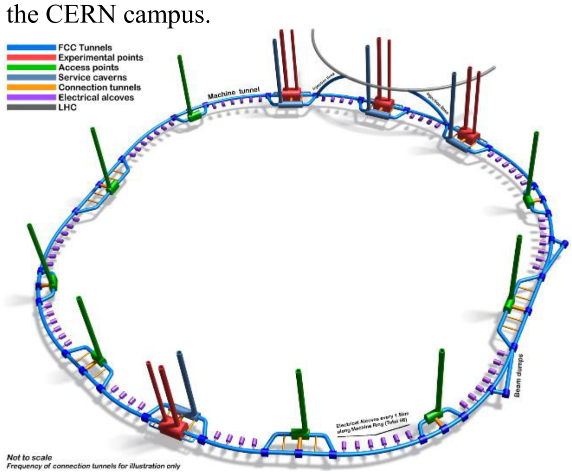

Figure 3: 3D schematic showing FCC baseline design.

Figure 3 shows the current baseline design consisting of 12 shaft locations with a total of 20 shafts. A large service cavern is located at each point and a large experimental cavern (shown in red) at each experimental point. Alcoves to house electrical equipment are located around the entirety of the tunnel at a spacing of 1.5 km.

During this stage of the study the dimensions and position of key infrastructure is under continual review in order to optimise the space and layout for all domains.

COST AND SCHEDULE ESTIMATE

The outcome from these developments has been used as the basis for an ongoing cost and schedule estimate. The primary aim of the study is to obtain an estimate within +/- 30 % for the baseline design: a single tunnel option, without inclined access tunnels, positioned below the level of the moraine below the lake. The secondary aim is to understand the impact on cost of schedule of some variations, such as a double tunnel option that incorporates a secondary access tunnel, a shallow option passing through the moraine under the lake, and a layout including inclined access tunnels to allow for accelerated construction. The results from this study are to be used to aid decision making on the design as the study progresses.

CONCLUSION AND FUTURE DEVELOPMENT

The results of the study so far provide a solid basis for early decision making on the study in terms of design, cost and planning.

However, there is scope for further investigation in these areas as the study progresses. The geological datasets used as the basis for TOT are based on existing CERN data from the LEP and LHC construction and interpretations from exploratory boreholes in the region. Whilst being an effective means of early analysis of options, more accurate geological data will have to be employed prior to any conclusive decisions on position. Eventually a full ground investigation campaign will be required. In addition, at this early stage the structural concepts are based on previous experience at CERN and other similar projects. These concepts need to be reviewed and verified in the future, particularly for the very large span caverns. The ultimate decision on the dimensions of the structures will involve an iterative process assessing the added value of increased space against the cost, schedule and construction risk implications.

REFERENCES

[1] C. Cook, B. Goddard, Ph. Lebrun, J. Osborne, Y. Robert "Civil Engineering Optimisation Tool for the Study of CERN's Future Circular Colliders," *in Proc. IPAC15*, Richmond, Virginia, 2015.

[2] GIBB-SGI-Geoconsult Joint Venture, "LHC Civil Engineering Consultancy Services. Package 2. Geotechnical Interpretative Report," unpublished.

[3] Amberg Engineering, "Comparison of 100 km FCC Options from an Engineering Perspective," unpublished.

[4] M. R. G. Anagnostou, "TBM drives in squeezing ground - Shield-rock interaction," in *AFTES Congrès Internationale*, Paris, 2008.