CIVIL ENGINEERING OPTIMISATION TOOL FOR THE STUDY OF CERN'S FUTURE CIRCULAR COLLIDERS

C. Cook, B. Goddard, P. Lebrun, J. Osborne, Y. Robert, CERN, Switzerland
C. Sturzaker, M. Sykes, Y. Loo, ARUP, UK
J. Brasser, R. Trunk, AMBERG, Switzerland

Abstract

The feasibility of Future Circular Colliders (FCC), possible successors to the Large Hadron Collider (LHC), is currently under investigation at CERN. This paper describes how CERN's civil engineering team are utilising an interactive tool containing a 3D geological model of the Geneva basin. This tool will be used to investigate the optimal position of the proposed 80 km-100 km perimeter tunnel. The benefits of using digital modelling during the feasibility stage are discussed and some early results of the process are presented.

INTRODUCTION

A five year international design study at CERN to investigate the feasibility of 'Future Circular Colliders' (FCC), potential successors to the Large Hadron Collider (LHC), began with a kick-off meeting held in Geneva in February 2014. The emphasis of the study is on a hadron collider with a centre-of-mass energy of the order of 100 TeV in a new 80 km – 100 km tunnel as a long-term goal. The design study includes a 90-350 GeV lepton collider, seen as a potential intermediate step. A lepton-hadron collider option is also being examined.

By the end of its construction in 2008, civil engineering accounted for around one third of the consolidated project cost of the LHC. Therefore, significant importance is placed on the civil engineering design when investigating the feasibility of the FCC. The earliest stages of any construction project offer the most opportunity for maximising quality and reducing total project costs. With this in mind, CERN is working in partnership with world leading engineering consultancies to utilise the latest methods and technology in order to ensure the best possible outcome from the first stages of design.

This paper describes the use of an interactive tool containing a 3D geological model of the Geneva basin. The Tunnel Optimisation Tool (TOT) is being used to assess the feasibility of the designs of the FCC study currently under study and their orientation with respect to the geology, terrain, surface constraints, their connection to the LHC and other siting considerations.

STUDY SCOPE

The Leman Basin, which contains the LHC, is surrounded by natural formations creating sensible boundaries for the FCC study area. Previous experience from the construction of CERN's previous particle colliders, LEP and LHC, has shown that the properties of the Leman Basin sedimentary rock, known as 'molasse', provide good conditions for tunnelling. During the excavation of the tunnel for CERN's Large Electron-Positron (LEP) collider, significant problems were caused by water ingress from the limestone formations in the Jura mountain range which lies to the west of Geneva.

For this reason, one of the primary aims when positioning the FCC tunnel is to maximise the fraction of the tunnel length in the molasse rock and minimise that in the limestone. Another primary concern is to orientate the tunnel in a way that limits the depth around its perimeter, therefore minimising the total depth of the shafts. These two primary concerns lead to natural boundaries in the form of the Jura range to the northwest, the Vuache mountain to the southwest and the Pre-Alps to the southeast and east. A boundary is placed in the north due to the increasing depth of Lake Geneva in the northerly direction.

THE DIGITAL APPROACH

The very first stages of a construction project offer the highest opportunity for overall reduction of cost, schedule and environmental impact (Fig. 1). A digital approach to the FCC feasibility study has enabled the CERN civil engineering team to extract the maximum value from the large amount of available data relating to the terrain, geology, hydrology, environment and built-environment of the Geneva basin, including man-made hazards such as geothermal boreholes. Locating the optimal position for any given design of the FCC tunnel requires all elements of this data to be analysed simultaneously.

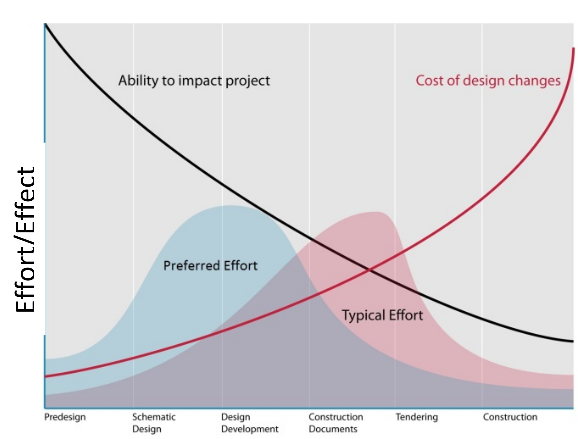

Figure 1: Macleamy's Curve (2004) from the Construction Users Roundtable

ISBN 978-3-95450-168-7

THE TUNNEL OPTIMISATION TOOL (TOT)

The Tunnel Optimisation Tool (TOT), developed specifically for the FCC study by the engineering consultancy ARUP, is based on an open source Geographical Information System (GIS) driven technology stack. GIS computer systems enable multiple sets of data to be arranged spatially, usually together with a physical or topographical map, all of which can then be manipulated, managed and analysed concurrently. For TOT, this means the user is able to input any size, shape and position of tunnel and to instantly see how this interacts with the geology, terrain, the environment and the build-environment in the study area. The more features that are included in the tool, the more powerful it becomes.

The functionality of TOT has developed continually since its inception and will continue to develop as the needs of the study evolve and/or when new data is incorporated into the tool. The current functionality can be divided into the following categories:

User Inputs

Design selection – Once a tunnel design is uploaded into the database it can be selected for analysis within TOT

Alignment – various parameters can be altered to position the FCC tunnel within the geology of the study area. These parameters include the position of the tunnel in the x,y plane, the azimuth (rotation in the x,y plane), the slope angle and the depth of the tunnel at its centre

Shaft positions – Each of the 12 shafts can be moved individually along the perimeter of the tunnel. If a shaft falls on a building (constructed or with planning permission) this is indicated to the user

Query – The percentage of the tunnel travelling through environmentally protected areas is given as well as the number of geothermal boreholes within a given radius of the tunnel that is specified by the user

Alignment Location

The interactive map performs as an input and an output. The position of a tunnel in the x,y plane can be easily altered by the user and each layer within the database can be turned on or off to be used as a visual aid.

Shaft Data Output

The depth of each shaft is given in tabulated format. This is further sub-divided by the geology intersected by each shaft. The total and distribution of the shaft depths is one of the indicators to the user of the cost/risk of a particular tunnel alignment.

Alignment Profile

A projection of the tunnel along its perimeter, plotting the position of the tunnel with respect to the geological rockheads and the ground surface.

Tunnel Geology Data Output

The geology intersected by the tunnel is given as percentage of the tunnel perimeter. Along with the shaft depth and geology data, this is a key indicator to a user of the cost/risk of a tunnel alignment since minimising the length of tunnel in limestone is a main aim of the feasibility study

Data Extraction

Detailed data for a given alignment can be downloaded from TOT in an excel format for further analysis of an alignment outside of the tool.

DATA

Datasets are referred to as ‘layers’ and can be displayed in various forms including single points, polylines, raster overlays or complex surfaces in three dimensions.

The geological contours are constructed using data from various studies in the region including those for the construction of the LEP tunnel at CERN as well as prospection for petroleum. These studies provide rockhead levels from exploratory boreholes and seismic lines that have been interpolated throughout the region by local geological consultant to create continuous 3D surfaces. The remainder of the spatial data has been sourced from French and Swiss geological agencies.

ANALYSIS OF RESULTS

Given the high number of variables and multiple objectives for optimisation (minimise shaft depths, minimise tunnel length in limestone, minimise length, curving radius and slope of injection tunnels from the LHC etc.), some form of detailed analysis is required to make a comparison between any two solutions. Comparison also needs to not only be made between two positions of the same tunnel but also between two tunnels of different perimeter lengths.

The engineering consultancy, AMBERG have compiled a list of factors related to the cost/risk of construction each element of the FCC project (tunnel, shafts & caverns) which are based on engineering experience of tunnelling projects. The data from TOT is extracted and weighted by the relevant factor, giving a total cost/risk value to any given solution.

An alternative method of analysis is also under investigation. This is the use of an optimisation algorithm, ROXIE, used previously for the optimisation of magnet design at CERN [1]. Based on a set of pre-defined objective functions, it may be possible for TOT to search for the optimal position of the FCC tunnel mathematically, through deterministic (e.g. maximum gradient) or genetic algorithms.

EARLY RESULTS

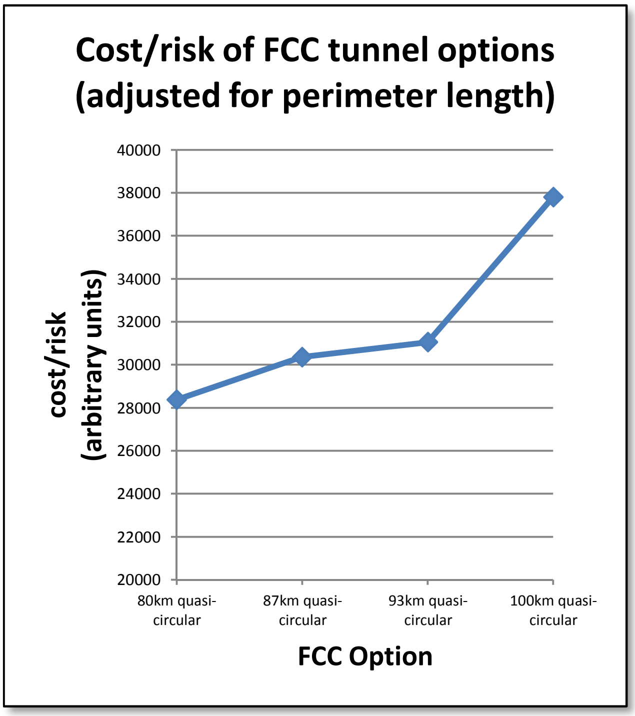

Figure 2: Cost/risk adjusted for perimeter length for the four tunnel options under study. The figures give an indication of the suitability of a particular option to the geology and terrain of the Geneva Basin.

The initial results of the comparison between the 80km, 87km, 93km and 100km tunnels can be seen in figure 2. All these tunnels lie on a plane with variable slope never exceeding 1 %. There is an inevitable linear increase in the cost/risk of any solution which relates simply to the extra length of tunnel required as the perimeter of the tunnel is increased from 80 km to 100 km. This linear increase in cost/risk has been removed from the results above to leave a measure of how suitable the tunnel lengths are for the geology and terrain of the FCC study area, or how well they 'fit' into the Geneva basin. However, the results show an increase in cost/risk still remains as the tunnel length is increased from 80 km – 100 km. This is a consequence of the larger tunnels extending further north and therefore travelling under a deeper section of Lake Geneva. This leads to increased tunnel depth along the length of the tunnel and consequently increased shaft depths. The 100km option is also penalised in this analysis for part of the tunnel intersecting with the Jura limestone, something which the other three options are able to avoid.

An example of a solution for the 100km option is shown in Figure 3.

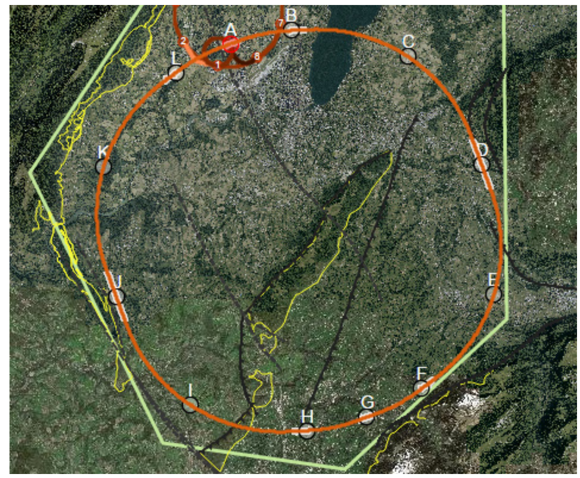

Figure 3: Siting solution and alignment profile of 100km option

LATEST STUDY CONCLUSIONS

The Tunnel Optimisation Tool (TOT), developed by ARUP, has enabled the civil engineering team at CERN to extract the maximum amount of value from early project data. From this, a position within the study area that gives the least cost/risk has been established for each of the options under study. These have been compared using a weighting system devised by the engineering consultancy, AMBERG and based on previous engineering experience. The results show that due to the need for them to extend further north into a deeper part of Lake Geneva, the larger tunnel options suffer from increased tunnel and shaft depths. Eventually, this has to be balanced against the benefits for accelerator performance and ultimate physics reach of a longer tunnel to give the option with the greatest cost-value benefit.

REFERENCES

[1] S. Ramberger and S. Russenschuck, "Genetic Algorithms for the Optimal Design of Superconducting Accelerator Magnets", CERN, European Organisation for Nuclear Research, Proc. of EPAC98, pp. 2014-2016, 1999

ISBN 978-3-95450-168-7