The construction of the tunnels and shafts for the project XFEL (X-Ray Free Electron Laser)

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ABSTRACT

With the European XFEL a unique free-electron laser Research Centre in the area of Hamburg, Germany, will be erected.
The facility consists of a two kilometer long accelerator tunnel, five finger tunnels starting from the end of the accelerator tunnel and leading to the underground experimental hall, a number of underground halls and shafts as well as additional infrastructural installations on the ground surface. The overall construction length of the facility is about 3.4 km. The tunnels are situated about 6 to 30 m under the surface underneath the ground water level. The construction pits are up to 40 m deep. The demand of straightness and therefore the demands on the tolerances of the construction is extremely high.
The construction started 2009, initial operation will be in 2014. The tunnels are driven with hydroshield TBM's with segmental lining.
The Paper will describe the experience gained in the first 3 years of work.

INTRODUCTION

A new physical high-performance facility for research with light is being produced at the German Electron Synchroton DESY in Hamburg in the form of the European X-Ray Laser XFEL. With its extremely short and intensive x-ray flashes nuclear processes can be observed in real time.
The DESY in Hamburg, Germany is a worldwide accepted research center for physics concerning to particle, acceleration and laser technology.
The European X-Ray free electron laser project (XFEL) is located on the border between the states of Hamburg and Schleswig-Holstein in Germany. The bulk of the plant will be built underground in tunnels and shafts. Access to these structures is via the three sites Bahrenfeld, Osdorfer Born and Schenefeld, on which special facilities and additional infrastructures will be built. 13 countries are shareholders of the European XFEL GmbH.

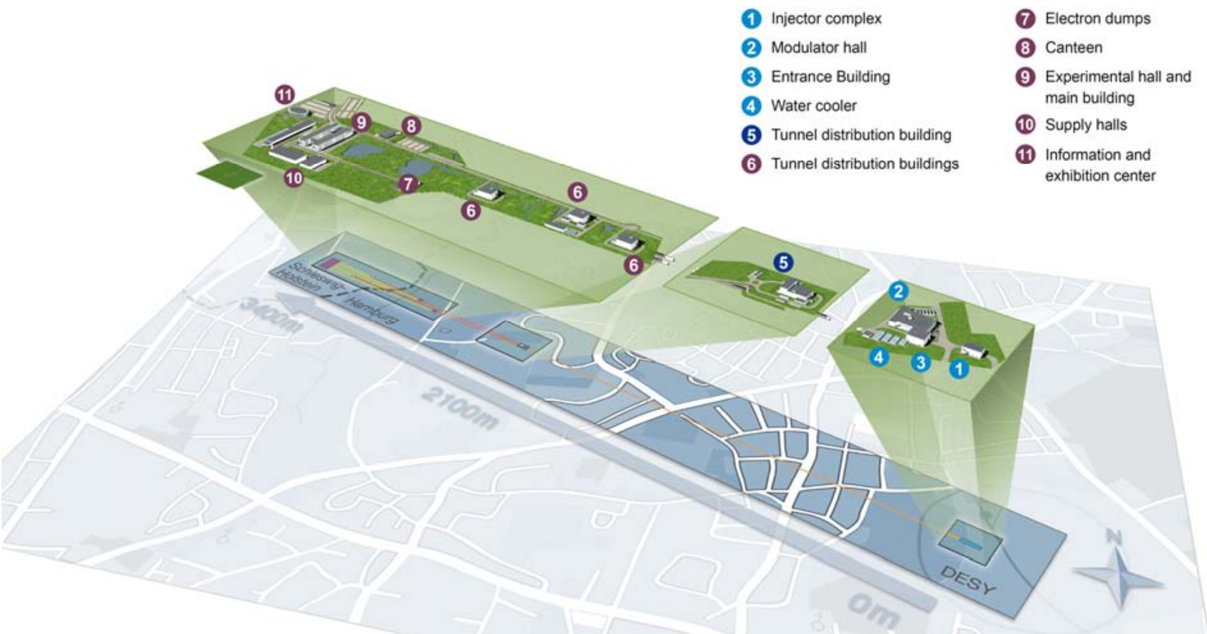
The XFEL structure will be constructed in two stages, with the 1st stage being the accelerator tunnel, the tunnel branch, the first experimental hall, a part of the facility buildings and the necessary outbuildings to operate the plant. The 2nd stage includes the second half of the tunnel branch, the second experimental hall as well as the infrastructure buildings. These will be built at a later date. The design fort he necessary tunnels and shafts has not already started.

The Linac tunnel XTL follows the direction of the electron beam of the injector XTIN. Herein all essential components necessary for the acceleration of the electron packages in the facility XFEL have been installed with the exception of the source to generate the electron beam.

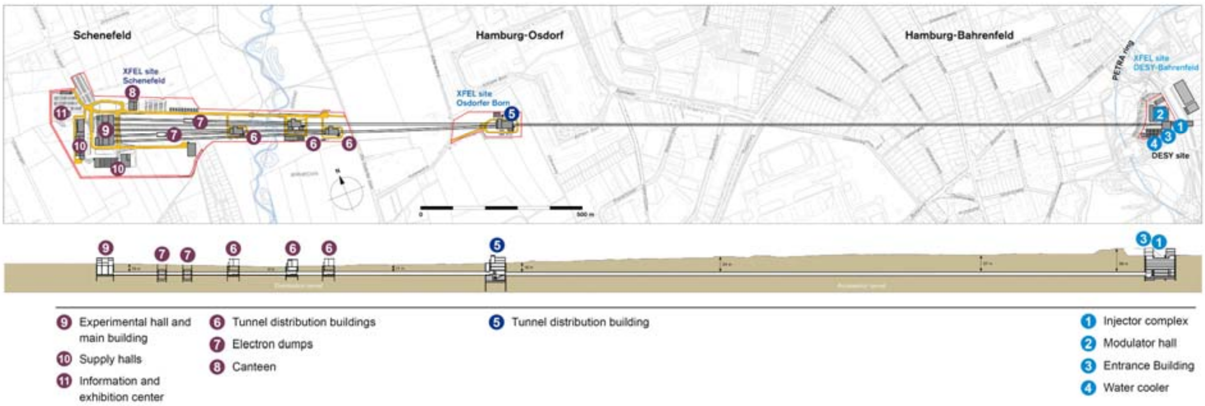
To supply the experiments in the experimental hall with radiation, the electro beam which is generated in the linear accelerator will be directed on to various kinds of X-rays undulators. This serves the branched structure, which consists of branching ducts (XS1-4), which includes associated halls (XHE1-4), absorber shafts (XSDU1 and XSDU2), and undulator and photon tunnels (XTD1-10).

Already in the XTL tunnel the electron beams are separated into three distinct beams. One of them runs in the XTD20 tunnel, which is the connecting tunnel for the prospective expansion stage 2. The other two electron beams pass through two separate undulators and each end up in an absorber (XSDU1-2). In order to divide the rays a shaft structure is needed at the mouth of the tunnel which then separates into two new tunnels.

The design of the construction was carried out by Amberg Engineering AG in an engineering JV association. Amberg Engineering AG is responsible for the design and site/construction supervision. An overview showing the facilities is given in pictures 1 and 2.



Picture 1: XFEL - Overview with visualisation of the buildings on completion



Picture 2: XFEL – Cross section with visualisation of the buildings on completion

PHYSICAL BACKGROUND

At the European XFEL ultra short X-ray flashes are produced. To generate the X-ray flashes, firstly the electron packets are accelerated to high velocities within the XTL tunnel and finally with specifically positioned magnets are steered into the tunnels XTD 1 - XTD 5.
Thereby small particles of light are emitted, which are increasingly strengthened, until finally they create an extremely short and intense X-ray flash. Using the X-ray flashes, molecular structures become visible and thus can be explored.
With these X-ray flashes, for example; the atomic details of viruses can be recognized, the molecular structures of

cells deciphered, the making of three-dimensional images from the nanocosmos can be made, as well as the filming of chemical reactions and the investigation of the inner workings of the planet.

UNDERGROUND

Geological conditions

The entire XFEL section lies in glacial deposits of sand, pebbles and cohesive soils, which are partly in a ring formation in the Tertiary substrate. The tunnel alignment is thus mainly in marl carrying groundwater of Pleistocene sands and gravels, and lies partly in tertiary mica fine sands.

In addition, one expects localized and limited disturbances to occur of homogeneous layers through sand, peat and stones of all sizes. The glacial marl is stored with water-bearing sand belts / sand-beds, and stones up to the size of blocks (boulders) are to be expected.
Since the tunneling will to a large extent be carried out in glacial deposits, an overall high abrasiveness is to be expected.

The covering of the tunnel is about 6 m to 38 m, but mainly a covering of 10m, 12m will be executed. The low coverage of 6 m is at the lowest point of the route, which is conditional on the crossing of the Düpenau. The catchment area of the Düpenau is characterized by large sealed areas. As a rule it carries a few liters per second and the water level averages a few centimeters. In heavy rain or during prolonged periods of rain the Düpenau can burst its banks, which means that the river flow increases to 2.5 m/s.

Groundwater

In the area between the DESY site in Hamburg Bahrenfeld and the border to the municipality of Schenefeld there are "free" groundwater conditions, ie, the existing water table and the piezometric surface are identical.
Minor water-permeable layers at the earth`s surface cause pressurized groundwater conditions to exist in the surrounding areas of the Schenefeld building site.

Pollution

Contamination
The tunnel alignment passes through old deposits, which were caused by the refills of a former sand mining pit. Additional information on suspected site contamination does not exist.

Groundwater Analysis
The groundwater in the area of the tunnel XTL, XTD1 and XDT2 in terms of hydrologic analysis has been shown to be moderately corrosive to concrete to DIN 4030-1. In the area of the tunnel XTD 3 - XTD 10, the groundwater is mostly not considered to be corrosive to concrete. Only in the area of the Düpenau can it be considered to be weak to moderately corrosive.

Ordnance
In the Hamburg metropolitan area no suspicion exists for explosives. In the Schleswig-Holstein part, soundings were made in the construction area by the Ordnance Service for discarded munitions which have been secured.

CONSTRUCTION

Injector

The injector consists of the Injector shaft XTIN, Injector XTIN tunnel and the entry shaft XSE and defines the beginning of the XFEL installation. During the construction phase, it serves as the end shaft for driving the XTL. The injector complex will be installed in an open pit as a massive reinforced concrete structure with a total of seven stories below ground.

Shafts XS1 - XS4
All excavations are done in the so-called slurry wall trenching method, that is, without sinking large areas of ground water, and without the use of rams or sheet piling.
At all beam branches shafts need to be arranged. In addition to beam branching, the shafts generally serve as access to the tunnel for persons and material as well as for the services needed in the tunnel (electricity, water, ventilation, etc.). During construction, they serve as necessary start and end shafts for preparatory work for the tunnel.

The lowest floor of each shaft with the beam level is separated from the upper floor by a radiation shield cover. This cover will be made of ordinary concrete with a thickness of 2.0 meters, the necessary opening for installation will have removable stones shaped, such that no continuous vertical gaps are formed.

The requirement is that the tunnel downstream of the beam to the shaft can be traversed individually at any one time with ongoing operations in the neighboring tunnel and shaft. This requires a separate beam protected anteroom within the shaft to the tunnel. This will be separated by an angled access through massive concrete from the main shaft region. The angled access will be made up of movable concrete shielding pieces so as to facilitate a straight passage to the shaft for the transport of bulky items. In the area of the anteroom installation holes will be arranged.

The shafts each have a separate security stairway and a fire brigade lift. This means that an additional room with positive pressurized ventilation at the exits of each level has been arranged. The lift's switch gear includes a safety interlock so that passage is excluded through the Interlock area during operation.
Outside the shafts between the tunnels is an additional shield of heavy concrete, which will be placed in the feeder areas to ensure the accessibility of the photon tunnel with simultaneous operation of the adjacent tunnel.

The retaining wall of the shaft is planned as a waterproof, internally stiffened diaphragm wall. The sealing of the pit from below shall be effected by an underwater concrete base. For the entry of the tunnel boring machine in each end wall an appropriately prepared "window" reinforced with fiberglass will be provided in the trench wall.

The final shaft structure will be made of reinforced concrete. The outer building walls are concreted directly against the trench wall enclosure and will be formed with waterproof concrete.

The shaft XS1 will be larger than the other shafts, because it has 3 tunnel branches. The third branch, the tunnel XTD 20 and the associated second branch construction will be installed during the second stage of construction. It also includes a beam absorber shafts like the dump-pit. The shaft will have a seal in the form of a deep set base.

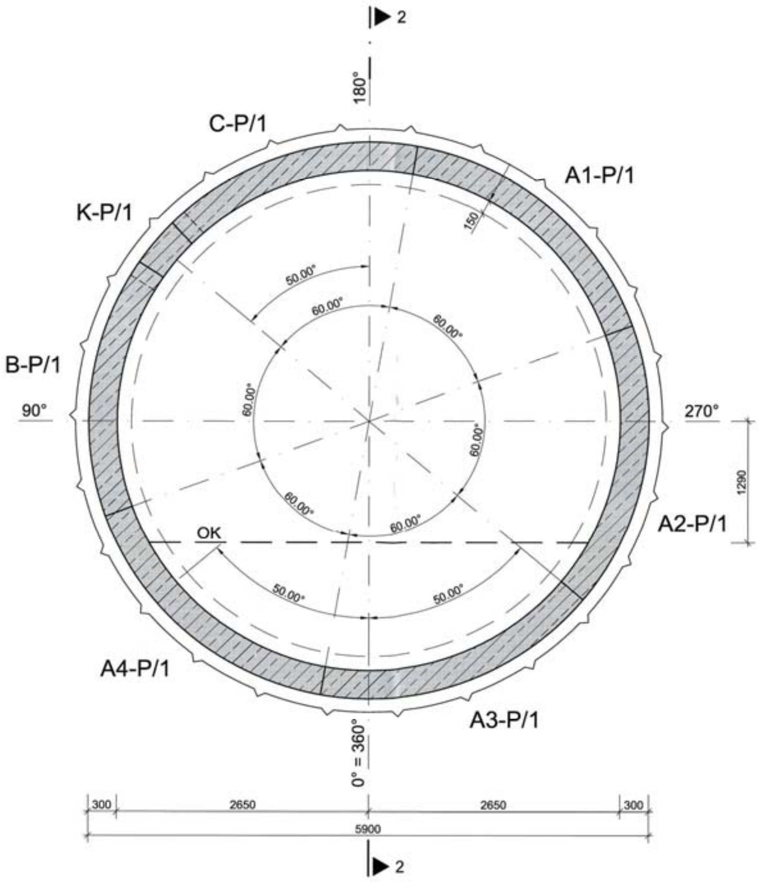
The beam absorber shafts will not be accessible from the upper surface in their final state. After passing through the undulator stretch the electron beam is no longer needed. At this time it has a power of 300 kW and therefore must be guided into a beam absorber. This dump pit consists of a graphite core, copper jacket and cooling coils and can absorb the resulting radiation.

Experimental Hall
The experimental hall will be built as a reinforced concrete structure in a water tight excavated pit, which consists of an anchored underwater concrete base enclosed by diaphragm walls.

Tunnels
The tunnels will be produced with two shield tunnel boring machines working underground and in parallel. The tunneling will be done with a tunnel boring machine with active tunnel face support.
The tunnels will be constructed as single skin lining segments in water-impermeable concrete and provided with circumferential sealing profiles.

When the excavations are ready for tunneling to start the two tunnel boring machines - the larger one with an outer diameter of 6.17 meters, moves toward the Osdorfer Born site, the smaller one with an outer diameter of 5.48 meters working under the Schenefelder site. After completion of a tunnel, the tunnel boring machines will be transported back into the respective starting positions and then go to the next tunnel stretch. Once an excavation is no longer needed for the tunnel as the start or destination of the tunnel boring machine, it will be developed as an appropriate underground structure.

The tunnel lining will be assembled with tunnel segment produced out of reinforced concrete. The thickness of the lining is 300 mm and the width of one ring is 1500 mm. The ring division is constructed with 6 normal and 1 little keystone. It is shown in picture 3.



Picture 3: XTL-Tunnel, ring division

Lengths of the tunnel sections are:

- XTL 2011 m
- XTD1 480 m
- XTD2 594 m with an outer diameter of 6.17 m.

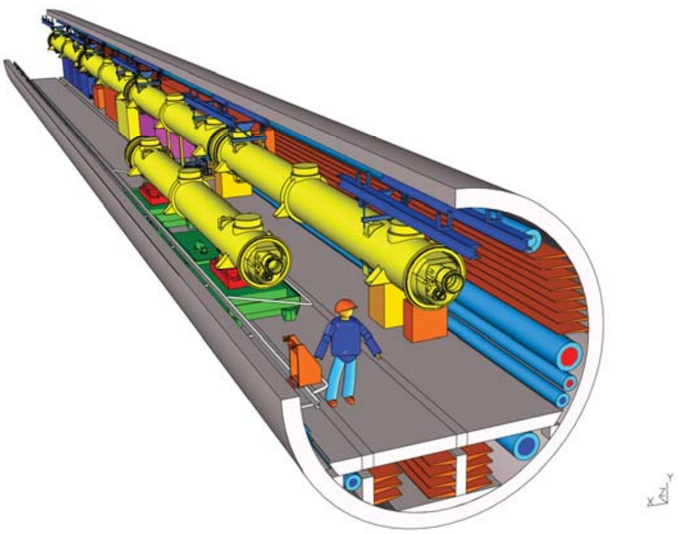
- XTD3 263 m
- XTD4 301
- XTD5 204 m
- XTD6 661 m
- XTD7 137 m
- XTD8 365 m
- XTD9 545 m

- XTD10 221 m with an outer diameter of 5.48 m

For reasons of radiation protection, without additional measures, it is necessary to provide a minimum cover above the tunnel crown of approximately 6 meters to the surface. The depth of the tunnel will be fixed by the lowest point along the tunnel routes. This local low point is in the area of the Osdorfer Feldmark Düpenau.

The course of individual tunnel sections is absolutely straight i.e the tunnels do not follow the curvature of the earth. All tunnel axes are, apart from any vertical Tunnel deviations, parallel to the beam plane which is oriented exactly tangential to an equi potential surface of the earth's gravitational field.

A detailed analysis of the use of space in the tunnel XTL showed that the suspension of the main linear accelerator under the tunnel ceiling, particularly during maintenance periods has considerable advantages. For this purpose, steel bands will be included in part of the lining segments. They will be installed during the tunneling in the ridge area and allow the subsequent installation of the interior and make possible the exact location for the suspension of the main linear accelerator.



Picture 4: Visualisation of the technical equipped acceleration tunnel

The concrete and reinforced concrete work will include the production of the flooring in the tunnels. In the course of concrete and reinforced concrete work, the tunnel drainage system will be made.
In tunnel XTL condensation or water leaks will be caught at the low point in the tunnel section using barriers, which are arranged every 48 m. The accumulated water can be extracted with mobile pumps.
In the other tunnels, any condensation and water leakages will be collected at the lowest point of the tunnel section in a basin. It can be removed with a suction line. Cleaning shafts regularly spaced will be provided. In picture 4 the structural works and technical equipment are shown.

Pipe line excavation
Because of its depth, the tunnels lie mainly well under the pipe line zones. For the tunneling XTD1 and XDT2 a dirty water sluice DN 1000 will be excavated with a small clearance of about 1.23 meters. The sluice will be taken out of service during tunneling. The waters collected in the sluice will be temporarily maintained. Before beginning the tunneling of XTD the sluice will be filled so as to be ready for the tunneling work.
The permissible settlement of the buildings located above the tunneling line is 2-4 cm.

THE STATUS OF THE WORK AND OUTLOOK

The work is performed in parallel at three sites. First removal of soil began in January 2009 at the site DESY-Bahrenfeld. The end of construction work is expected in June 2014.

The Work on the accelerator tunnel started in January 2011, when the boring machine TULA ("tunnel for laser") began to dig its way from the construction shaft on the Osdorfer Born site to the DESY-Bahrenfeld site. Right behind the cutting wheel digging its way through the earth, more than 8 000 precast concrete segments were inserted to construct the tunnel wall. In July 2011, TULA reached its destination and was dismantled and removed from the construction site. The tunnel was then equipped with a flat floor made of concrete elements, which will later cover parts of the infrastructure.

The accelerator tunnel starts at the future injector building in DESY-Bahrenfeld and ends at a shaft in Osdorfer Born. Further towards Schenefeld, the tunnel branches into two and then eventually five tunnels. The construction of these photon tunnels, which lead to the future experiment hall on the Schenefeld site, is expected to be completed by mid-2012. The photon tunnels will later serve to generate X-ray flashes from accelerated bunches of electrons.

In June 2011 building construction has been started on the site DESY-Bahrenfeld. The entrance halls to the two shafts of the underground injector complex is currently being constructed. The construction of the modulator hall for the power supply of the plant, the erection of additional infrastructure facilities and the landscaping of the site will complete the construction work at the European XFEL site DESY—Bahrenfeld in the autumn of 2012.

AMELI is the German acronym for "At the end (there will be) light". It is the smaller of the two tunnel boring machines and drills the "fan" of altogether eight single tunnels underneath the future Schenefeld research campus. The construction of these tunnel sections will be finished in June 2012.—AMELI is currently constructing tunnel section XTD6, the last and longest one of the "fan". The tunnel sections XTD9, XTD10, XTD4, XTD8, XTD7, XTD5, and XTD3 are already completed.

On the Osdorfer Born site the XS1 will be erected by September 2012 parallel to current construction of the last tunnel.

The largest of the three sites is located in the south of the city Schenefeld (Pinneberg). Here, by August 2010 the excavation of the six pits had been completed. The last part of the construction work will start in May 2013 with the construction of the building above the ground level. A visualisation of the finished buildings aboveground and underground is given in picture 5.

Picture 5: Visualisation of the experimental hall aboveground (left) and underground (right)

The success of the project essential depends on the possibility to comply with the demands of straightness. The tolerances of the final construction are very small. So it will depends on the experiences and responsibility of the site supervision to finish this project in a satisfied way and for the satisfaction of our client.

LITERATURE

[1] Additional information is performed at the homepage of the project XFEL www.xfel.eu