TECHNICAL OVERVIEW OF THE PAL-XFEL CONVENTIONAL FACILITY*

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Abstract

Pohang Accelerator Laboratory (PAL) has finished construction of a 1,110m long 10GeV X-ray free electron laser (XFEL) linear accelerator building in FY2015. In order to secure high-sensitive of XFEL accelerating devices, more advanced and well proven technologies were adopted in the design of the building. These are the ground improvement underneath the tunnel and tunnel structure itself against the possible ground deformation, air conditioning system to maintain the temperature and humidity in the tolerable ranges and architectural zoning. In this paper we describe the features of design and construction of the XFEL accelerator building.

INTRODUCTION

The construction of PAL-XFEL Conventional Facility has been finished in FY2015. Since the XFEL devices have severe tolerance such as within ±50~200㎛ in alignment, the conventional facilities have to be designed and constructed within the criteria as shown in Table 1.

Table 1: The Allowable Criteria of PAL-XFEL Building

Character	Criteria
Depth of Tunnel Structure	1.5 ~ 2.0 m
Floor Flatness	< ± 4 mm / 10 m
Floor Levelness	< ± 10 mm / 1,110.8 m
Vibration	< 1㎛ (ptp)
Allowable Bearing Capacity	500 kN / m²
Floor Subsidence	< 2 mm / 10 years
Radiation (Outside of Tunnel)	< 10 mSv / 1 year
Wind Load	63 m / sec
Seismic Intensity	S : 0.19
Temperature Condition(Undulator)	25 ± 0.1 ºC (RH 50%)

SITE PREPARATION AND LAYOUT

XFEL building is located in the northern hilly area of the PAL site, where there is enough space for the 1,110m long building shown in Fig. 1. The ground under the tunnel floor slab (altitude: 60m above mean sea level) of PAL-XFEL site is geologically stable with solid base rock in most places.

Since the site is located in a hilly area and the 154-kV power transmission line cross the proposed PAL-XFEL building, site preparation work was started in October 2012 by cutting trees and relocating the transmission line. A total of 1.2 million m³ of soil has been removed to prepare the flat base area of the facilities. There is a main building containing the linac, undulators, and beamlines. Besides, there are also six utility buildings separated from the main building by a two-lane road in order to reduce the transmission of any vibrations induced from the motors, cooling towers, etc. in utility buildings to the machine floor in the main building. Cables, piping and air ducts are connected through 11 overpass bridges.

Figure 1: The site and layout of PAL-XFEL.

Replacement of Weak Ground

For reinforcing the weak ground of bearing capacity below 500kN/m² PAL tested four replacement materials including crusher stone+grout used in the undulator section of SACLA [1]. The piling method was excluded because the subsidence of replacement method was much smaller than the piling method in the SACLA building. All the materials were accepted in the elastic settlement test as shown in Fig. 2.

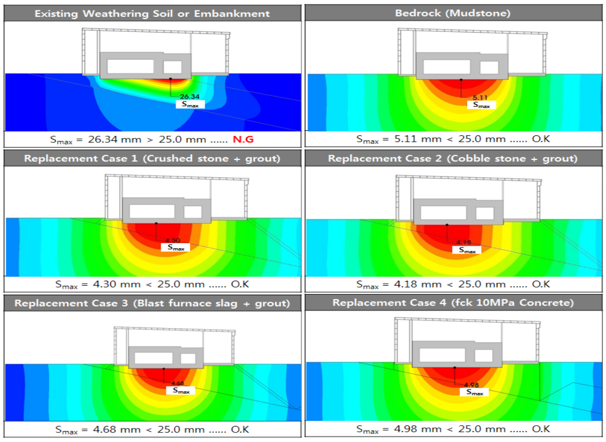

Figure 2: Elastic settlement simulation of replacement.

But concrete was found to be the most appropriate in the differential settlement test as shown in Fig. 3. This is because the settlement related parameter of concrete is similar to that of bedrock (mudstone). Therefore, PAL selected concrete as the replacement material moreover due to the advantage in construction period. When bedrock i.e., mudstone is exposed to water and air, slaking would arise and the engineering strength of mudstone

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would be reduced sharply. Therefore, after excavation, the 6cm thick protection concrete was casted at the excavated surface as soon as finishing the cleaning at almost the same time. The total volume of replacement and protection concrete used was approximately 24,000m³.

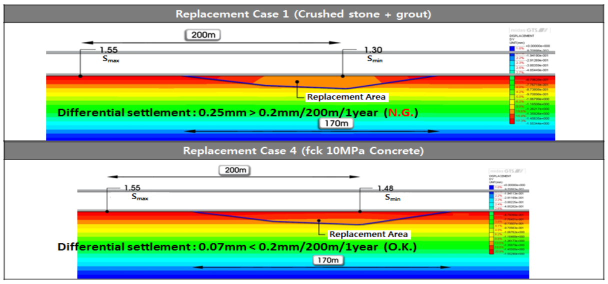

Figure 3: the differential settlement simulation of replacement.

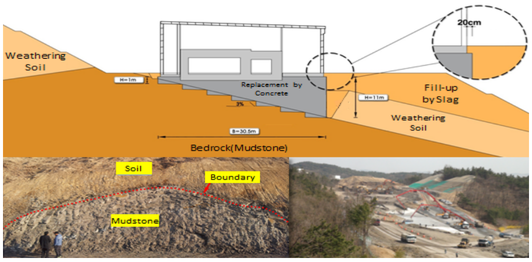

Figure 4: Cross section of replacement planning.

The cross section of concrete replacement underneath the building is shown in Fig. 4. And the longitudinal replacement survey configuration underneath 1km tunnel is shown in Fig. 5 and Fig. 6. Subsidence of 1km tunnel has been surveyed to be less than 1.5mm for two years. This small figure assures the replacement method was appropriate for the site.

TUNNEL STRUCTURE

The main building contains a box-shaped concrete tunnel in which all the XFEL machines such as linac, undulator, etc. to be installed. The thickness of the tunnel is 2m for the walls, ceiling and bottom slabs.

Since large amount of cracks were anticipated during the curing of this massive concrete, the ultra low-heat concrete using blast-furnace slag cement was chosen to reduce those anticipated cracks. To maximize the stiffness of the tunnel and hence to stabilize the machines in it in the vibrational view point the square box shaped linac tunnel is designed to be one body without any expansion joints in the cross sectional view. However, the undulator and BTL tunnels, which have the same thickness as the linac tunnel, have isolated floors from walls with expansion joints to reduce the transmission of any vibration transmitted through the walls and the ceiling from any dynamic power source, water pipes, etc. as shown in Fig. 9.

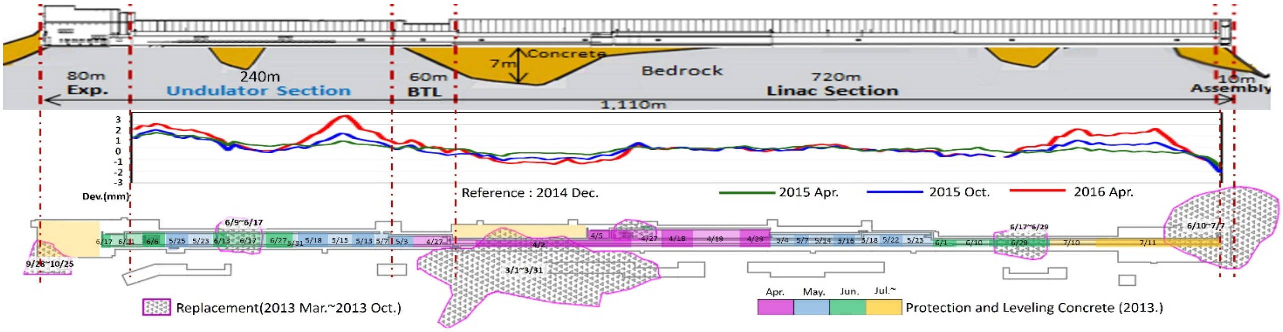

Figure 5: Areas of replacement and displacement survey graph.

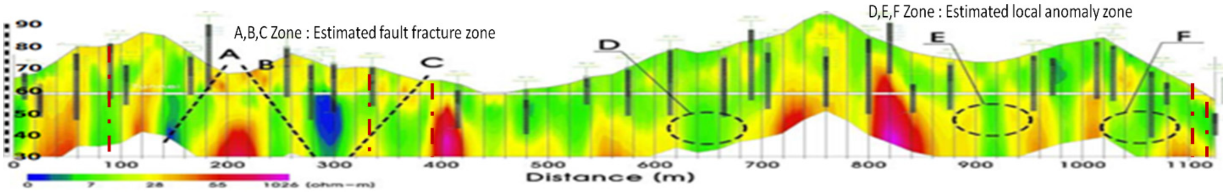

Figure 6: Result of electrical resistivity survey.

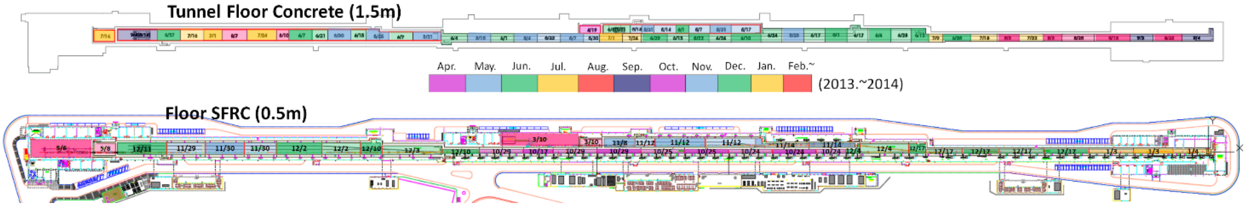

Figure 7: Period and interval of floor construction.

As for concrete job, 1km long tunnel has to be built with division of many sections in a particular sequence to reduce the cracks. To minimize the crack formation in concrete tunnel simulations of cracks were performed for a few numbers of span length of tunnel to be built at a time (a division of section). And the only 7.5m span length of tunnel reveals the figure of bigger than critical number, which means free from crack, as shown in Fig. 8. But due to short construction period 20m span length of tunnel was chosen to be built at a time (concrete work). The concreting sequence adopted was that the concrete for every other sections of tunnel were poured simultaneously and after maximum shrinkage occurred with enough curing time the rest section in between the other sections would be poured and cured as shown Fig. 7.

And further to minimize the random cracks in tunnel wall with temperature variation during construction and before operation of air conditioning, intentional crack inducing control joints were provided vertically at every 6.6m in wall structure. And, no intentional expansion and crack inducing control joint were provided in the floor slab structure because the temperature variation of bottom part of floor slab is not considerable.

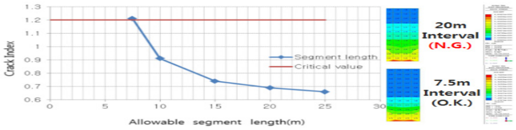

Figure 8: Crack simulation with construction joint interval.

As for the floor slab along all the tunnel, 2m thick concrete is separated by 0.5mm polyethylene film. The lower part 1.5 m thick concrete is normal concrete with sufficient strength. But, the 0.5m thick upper part of floor slab is not normal concrete but steel fiber reinforced concrete (SFRC) with higher strength and better looking surface than normal concrete. The impact resistance of steel fiber reinforced concrete (75kg/m³) is over 10 times higher than ordinary concrete. To make the surface of SFRC flat, laser trackers and track rails were used. The flatness of the floor was kept within ±4mm. The expansion joints of SFRC is approximately 40m and partially controlled with the configuration of the slab and layout of accelerating devices.

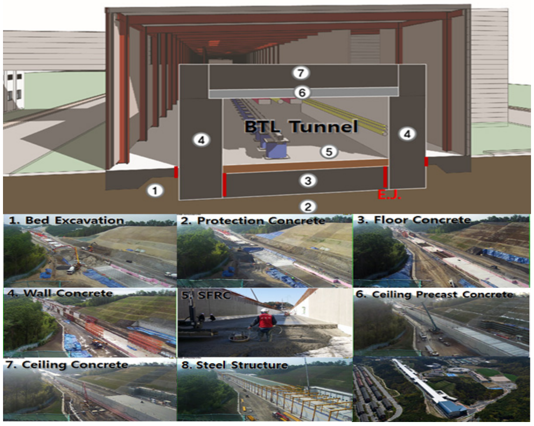

Figure 9: Construction procedure of the tunnel.

For better marking and setting the devices into the position self-levelling 3mm thick epoxy lining was made on the surface of SFRC. The total volume of concrete used is approximately 100,000m³ and the construction views in outstanding stages are seen in Fig. 9. The main steel structure of main building in which the tunnel is contained is so called pre-engineered steel beam system.

AIR CONDITIONING IN TUNNEL

To prevent the deformation of tunnel and dislocation of accelerating devices, it is important to make the temperature in and outside tunnel stable in a limited range. One strict condition applied to the building is the temperature stability of the undulator tunnel, because PAL-XFEL is using out-vacuum undulators; the requirement is 25±0.1ºC. Through the simulation shown in Fig. 10, the air volumn, the location supply air outlet, duct size and location of the air handling units were decided. Since the undulator is out-vacuum type, the air volume is bigger than any other laboratories due to operation range of ±0.1ºC [2]. Although the air handling units are located in the tunnel, the vibration is regulated below the standard of semiconductor clean room; < 0.2㎛ (ptp) because the wall hanged AHU is isollated by expansion joints from the floor of the tunnel (Fig. 11).

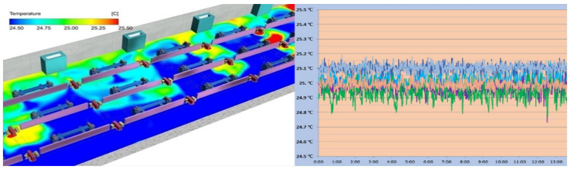

Figure 10: Temperature simulation and measurements.

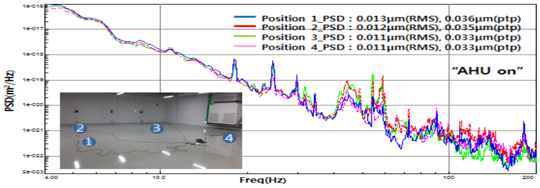

Figure 11: Measurements of vibration in undulator tunnel.

CONCLUSION

Before design and construction of PAL-XFEL building many important key points, such as tunnel deformation due to temperature fluctuation and geological problems, vibration problem, maintaining stable temperature in the tunnel, etc. were studied and summarized to incorporate into the design material. Most of the points were considered and materialized in the design and final construction. It is now being surveyed and monitored very regularly during the installation of the machine devices.

REFERENCES

[1] Yuji Ymano et al., "Design of XFEL Facility in Harima", MOPD010, EPAC'08.

[2] In Soo Ko, "Status of PAL-XFEL Construction", No.1, Vol.26, February 2016, Feature articles, AAPPS.