DESIGN OF LARGE-SIZED ACCELERATOR TUNNEL

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Abstract

There are several key points in designing the underground tunnel where large-sized accelerator is installed. The following two points are very important: (1) Transformation of the tunnel should be minimal, (2) Level of integrity and durability of the tunnel structure should be high. In order to accomplish minimal transformation of the tunnel and stable operation of the accelerator, we recommend not to provide the expansion joints in the tunnel concrete. As the result of structural analysis which we performed on temperature change inside the tunnel without expansion joints, we confirmed that there was few incidence of harmful cracks and transformation.

INTRODUCTION

In Japan, epoch making accelerator facilities such as J-PARC, X-FEL, GHMC(small heavy ion cancer therapy center in Gunma) have been constructed. R&D and design of ILC have been pushed forward by industry-university cooperation. On the other hand, as accelerator has become large, its performance has become inseparable from the design and construction technology of the tunnel where it is installed. This report introduces a few key points for underground accelerator tunnel design, especially the result of structural analysis to investigate the necessity of expansion joint in the tunnel that we performed using the structural model of J-PARC 50GeV synchrotron tunnel (see Figure 1, Figure 2).

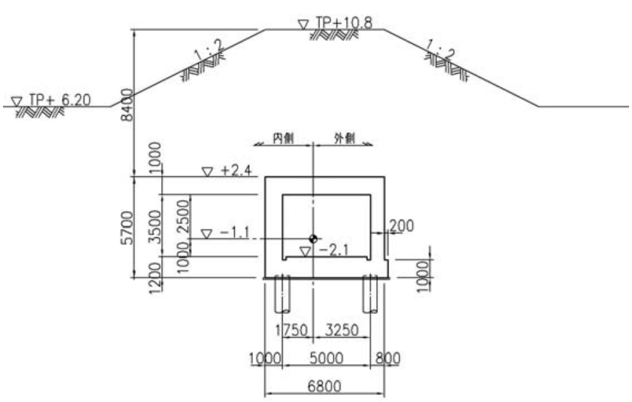

Figure 1: Cross-section of J-PARC 50GeV synchrotron tunnel

Figure 2: Bird's-eye view of J-PARC 50GeV synchrotron.

KEY POINTS OF UNDERGROUND ACCELERATOR TUNNEL DESIGN

In designing the accelerator tunnel, enough attention should be paid to the following points. The first point is to control transformation of the tunnel within a limit value to secure performance of the accelerator. The second point is to improve integrity and durability of tunnel concrete as much as possible. It goes without saying that integrity and durability of concrete are most important in terms of property and safety protection similarly as the concrete structures of civil engineering. However, it is particularly important that concrete which have very few cracks reduces penetration of groundwater into the tunnel and generation of radioactive waste water in the accelerator tunnel. In this regard, the accelerator tunnel is different from the transportation tunnel where some penetration of groundwater is permitted.

Transformation of the Tunnel

Transformation of the tunnel is influenced by various factors such as geological features, situation of subsurface water, temperature fluctuation inside the tunnel, change of live load to the tunnel and structure of the tunnel itself. In the case of the tunnel with the mat foundation, the tunnel might raise or sink in a short term by seasonal variation of groundwater level. If such a situation happens, the alignment or the stable operation of the accelerator may not be performed successfully. Then it is essential that the tunnel should have pile foundation which reaches to strong stratum. Furthermore, even if the tunnel has pile foundation, elastic deformation of piles can not be ignored when live load to the tunnel changes greatly. Therefore, the construction procedures should be planned carefully in such a way that great load changes do not occur for the tunnel after the installation or the alignment. On the other hand, in order to accomplish a smaller transformation of the tunnel and stable operation of the accelerator, it is important to consider whether to provide the expansion joints in the tunnel or not. Because, expansion joints are transformed by temperature change or earthquake and they may cause some obstructions such as cracks in concrete of the tunnel, penetration of ground-water into the tunnel, and uneven settlement of tunnel floor which give some troubles to the stable operation of an accelerator.

Integrity and Durability of the Tunnel

Integrity and durability of the tunnel can be expressed in other words whether there are few cracks in the cover concrete of the tunnel or not. In the J-PARC 50GeV synchrotron tunnel, low-heat cement was adopted and achieved some effect to reduce cracks caused by dry shrinkage. In addition, we decided not to provide expansion joints in the overall ring structure of the tunnel in lap length of about 1.6km, after we confirmed by structural analysis that harmful cracks shall not occur.

Structural Analysis

When construction of the accelerator tunnel is completed, temperature at both the soil around the tunnel and the space inside the tunnel is about 15°C. Therefore the temperature of tunnel concrete is assumed to be approximately 15°C. On the other hand, indoor temperature during accelerator operation will be controlled to be lower than 30°C. Therefore, the severest condition for the structural analysis is when the temperature of concrete rises from 15°C in early stage of construction to 30°C during accelerator operation. In this paper, axial direction analysis of the tunnel skeleton was carried out to examine how stress, displacement, crack of concrete change for early stage of the construction. The summary is as follows.

(1) Examination condition

- Structural analysis model of the whole ring tunnel consists of the curved parts and the straight line parts (see Figure 3)
- Structural members have spring of an axial direction and a right angle direction
- Linear thermal expansion rate of concrete: $1.0\text{x}10^{-5}$ (1/°C)

(2) Analysis application

Three-dimensional ground and structure seismic response analysis system code, DINAS[1] was adopted.

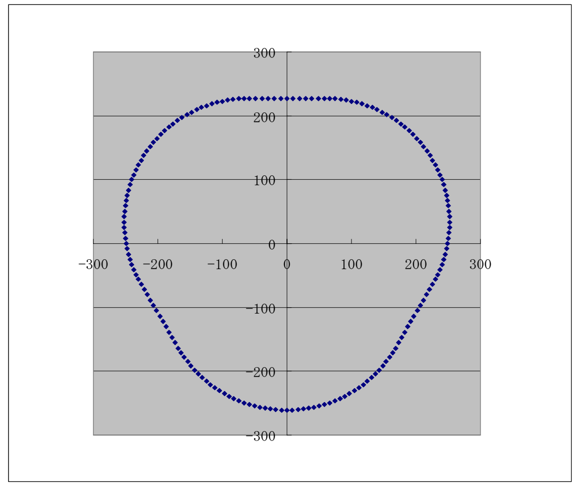

Figure 3: Structural Analysis Model.

(3) Examination results

- During accelerator operation, the highest temperature will be 30°C, and the mean temperature of tunnel concrete will be 27°C, as shown in Figure 4. The largest difference is 12°C during the maintenance over several months in winter season. In the case of the convection heat transfer rate =1, it takes about one month until the concrete temperature settles down to approximately 15°C.
- Even when the tunnel concrete temperature change reaches 12°C, as shown in table 1, the bending moment is enough smaller than the cracking moment. Therefore, it is assumed that concrete temperature changes will not cause cracks in concrete by on and off the accelerator operation.
- A ring tunnel mainly transforms to outside direction in a curved part, as shown in Figure 5, and the maximum displacement is around 4mm. The lap length of the ring increases by around 3mm. The average expansion and contraction rate (= $1.6\text{x}10^{-7}$ (1/°C)) for the whole laps is smaller enough than linear thermal expansion rate of concrete. Therefore, transformation in the ring direction is smaller when there is no provision of expansion joints compared to the case with the expansion joints. The expansion and contraction rate indicates the value of 5~$6\text{x}10^{-6}$ (1/°C) in the straight line regions (expansion area) and curved regions adjacent to the straight line regions (contraction area). When the concrete temperature change is 12°C, the maximum expansion and contraction of the ring are around 0.07-0.08mm per 1m.

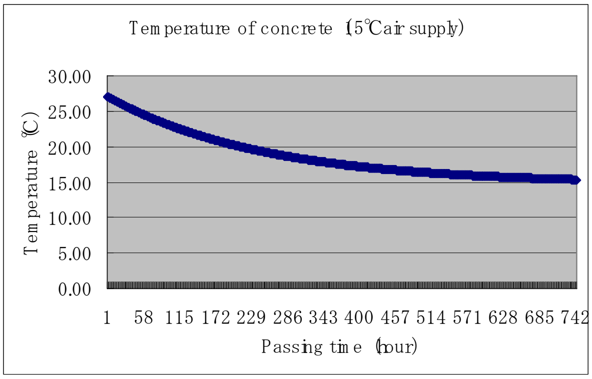

Figure 4: Temperature of tunnel concrete during maintenance of accelerator.

Table 1: Crack Moment and Bending Moment

Moment (KN・m)	Curve region	Straight region
Crack Moment	6.16E+04	4.94E+05
Bending Moment	5.14E+03	1.46E+04

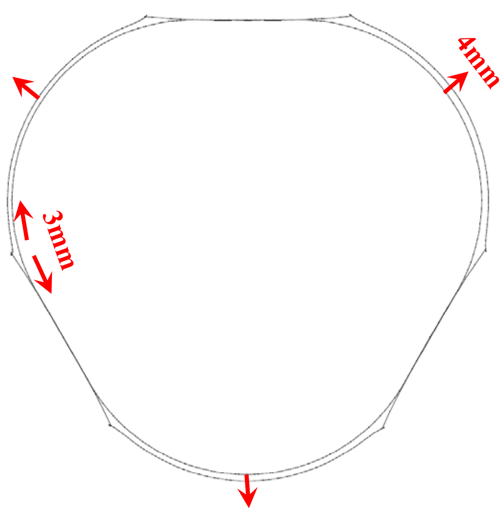

Figure 5: Transformation of the ring tunnel.

CONCLUSION

There are two important key points for designing the underground ring tunnel of a large-sized accelerator. First, transformation of the ring tunnel should be minimal. Second, level of integrity and durability of the tunnel structure should be high. Whether to provide the expansion joint in the tunnel or not is an important problem common to these points. As a result of structural analysis, we confirmed that there will be no incidence of displacement and cracks in the tunnel concrete without expansion joints.

ACKNOWLEDGMENT

We express my gratitude to the members of the Plant and Facilities Department of Administration Bureau in KEK, the clients of J-PARC 50GeV synchrotron.

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