A FOUR HUNDRED METERS LONG UNDERGROUND HLS AT XFEL/SPRING-8 SITE

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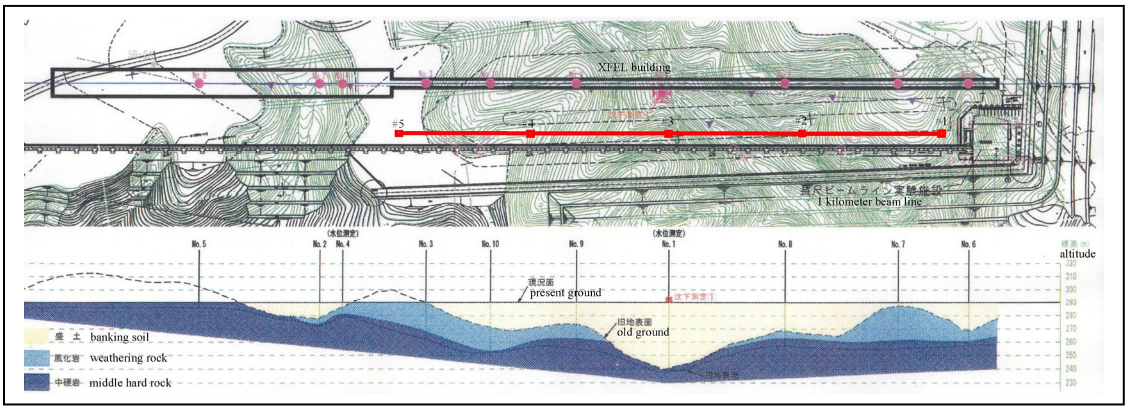

Fig.1 Site of XFEL/SPring-8 and the reference line of monuments

Abstract

A reference line of monuments is built at the SPring-8 site, on purpose to measure the ground movement at the XFEL site, and monitor the deformation of the XFEL buildings. At present, a 400m HLS (hydrostatic leveling system) is made, one meter beneath the surface of the earth.

The construction of the monuments as well as the HLS system is illustrated. Because the HLS system is built out of doors, severe temperature change usually limits its measurement capability. However, the measurement data show a promising result. With the HLS the daily ground movement or distortion for the length of 400 meters XFEL accelerator can be clearly seen.

INTRODUCTION

The XFEL/SPring-8 is built at the altitude of 290m, the same level as the SPring-8 storage ring. On this level, the ground in SPring-8 site is either excavated rock or banking soil. The building of XFEL accelerator tunnel is in the area of banking soil. It will be constructed by driving piles to the bedrocks.

To measure the ground movement at this site, and monitor the deformation of the building of the XFEL accelerator, a monument line 400 meters long is built. It is composed of 5 monument complexes in 100m intervals and connected with a HLS system. The monuments are parallel to XFEL accelerator tunnel, set on the places of geologically different ground (figure 1).

CONSTRUCTING THE MONUMENT LINE

The monument complex

The monument complex will comprise a height reference of the HLS (hydrostatic levelling system), and a transverse reference point for the measurement of GPS or laser system.

How to build the monument are based on following considerations. Because laser system will be used, the height of the monument should be high enough to not hit people's eyes. On the other hand, the HLS system is need to be buried into the ground as deep as possible to reduce temperature effect. According to previous data, temperature changes fifteen degrees yearly one meter below the ground level at the site of the storage ring. This will cause a level change of the HLS for 24mm if only take count of the expansion of water for a four hundred meter system.

The monument complex is actually built in a height of

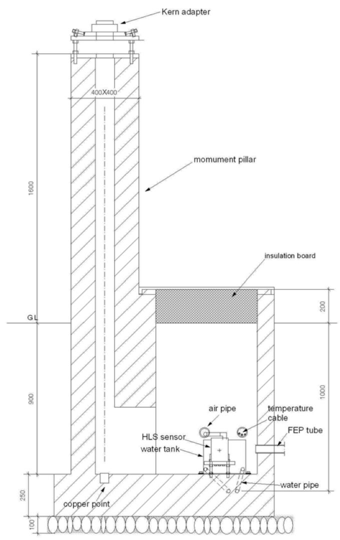

Fig.2 Sectional drawing of the monument complex

2.8m, with 1.6m above ground level and 1.2m underground (figure 2). Laser system, plus the fixture, will be in a height around 2m, high enough over people's eyes. On the contrary, the HLS sensor is set inside a pit 90cm deep. Although the temperature fluctuation become less when it goes deep into the earth, for the reason of cost, we chose the depth for the communicating pipes of one meter.

The monument has to be built heat insulation and waterproof. Underground part of the monument is the HLS pit. It is covered with heat-insulating board. And, it is painted with waterproof material and embedded with sheet at the bottom, to proof against underground water. In addition, the monument as well as the communicating pipe is buried in sand, in consideration of dredging the rainfall and protecting the pipes against surrounding pressure which may invalidate system's function (figure 3).

Fig.3 The HLS pit, lower part of monument, is buried underground.

The four hundred meters underground HLS

For the HLS system, full-filled type is chosen because the idea of using half-filled system is proved to be impractical. Half-filled type needs the pipe to be laid in identical height and building such a system therefore will be so expensive that we have to abandon it.

We adopted full-filled system and in the meanwhile made some compensative measures to reduce the temperature effect. For example, a water tank is used beside the sensor. Because the amount of water level fluctuation caused by temperaure is inversely proportional to the area of water's free surface, the tank is employed to increase the free area of water and it will reduce HLS level fluctuation by a factor of 13. Another effort is made to measure the temperature of the communicating pipes. In addition to measuring the temperature at the sensor bottom, temperature probes are extended to inner soil and attached to the pipes at several points, apart from the sensor for 5 to 30 meters.

A hundred meter long communicating pipes between monuments are buried one meter beneath ground level. The pipes for water and that for air are laid in same levels (figure 4). Water communicating pipes are twofold and

Fig.4 Communication pipes connecting HLS sensors are laid in same level of -1m.

Fig.5 Communication pipes, the lowers are for water and uppers are for air and cables.

Fig.6 Inside of the HLS pit

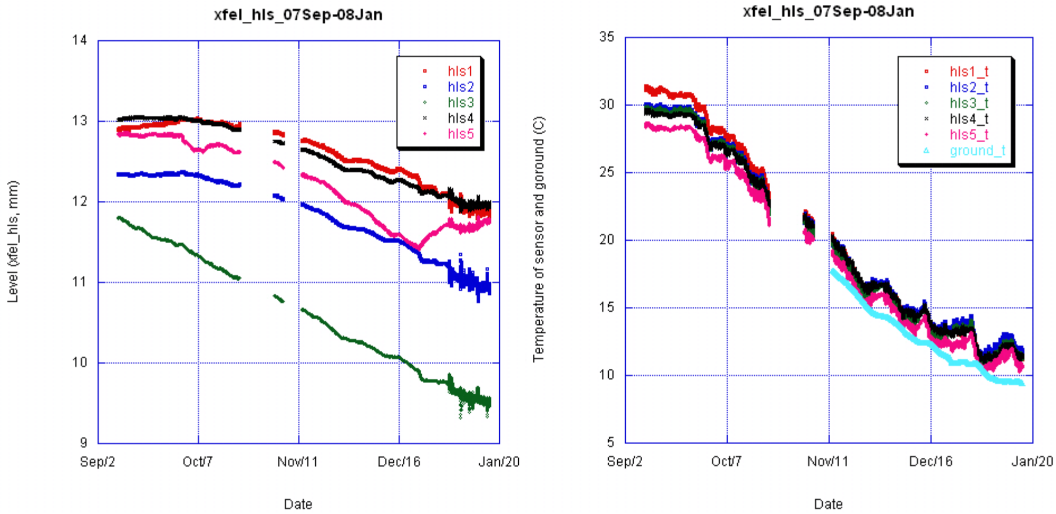

Fig.7 left: Measurement data of the levels of monuments from Sep. 2007 to Jan. 2008
right: Temperature at the sensor bottom and the pipe surface

made by hard type polyethylene of 19mm diametrical. The communicating cubes for air are relatively soft. So, FEP tubes are employed to protect the air tube and cables from ground pressure (figure 5).

Inside the HLS pit are the sensor (15mm range FOGALE), the water tank with a size of 250W250D200H and the bump for water circulating (figure 6). Cables of temperature sensors distributed to pipes are relayed in the pit and are led to a house at the 1km beam line, where has data acquisition units

MEASUREMENT WITH THE HLS

Measurement data

The underground HLS was completed in June 2007. We got some trouble in the HLS pit when driving in the anchor bolts that fix the sensor. Some crack appeared and lead to underground water permeated the pit in the time of heavy rain. Continuously data collecting was started from September. Figure 7 show the measurement data from Sep. 2007 to Jan. 2008. 'Hls' indicates the distance between sensor electrode and water surface, shows the level of a monument. 'Hls-t' is the temperature at sensor bottom. And, the 'ground-t' is the temperature measured at a point of the communication pipe in the soil, five meters apart from hls3.

Temperature dropped for 20 degree in this period. Therefore, besides level movement the absolute distances between the sensor electrode and water surface should contain the temperature and evaporation effect of water. To obtain real movements of the monuments, these effects should be removed from raw data.

The amount of evaporation is estimated by measuring the level difference of two seasonally equal temperature points in June and October. As a result, the water surface drops by 2.4μm/day (0.8 cubic centimeters per day) for the evaporation.

The level change caused by the volume expansion of water, or the temperature effect, is deduced from the data of November and December, taking away the amount of water evaporation. The measurement indicates that water level increased (distance decrease in the figure) as the temperature become low (figure 8). And, the level change

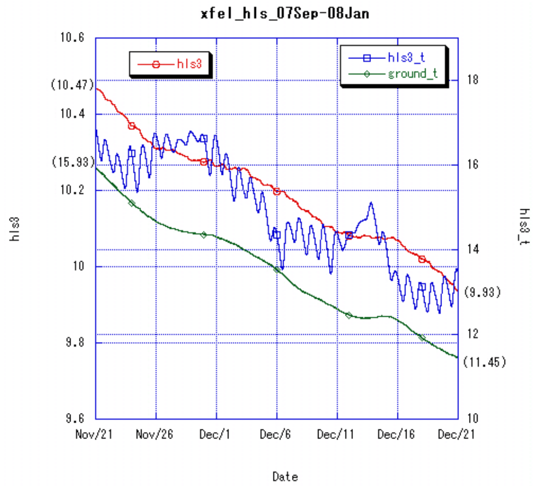

Fig.8 HLS measurement is correlative with the temperature at the pipe.

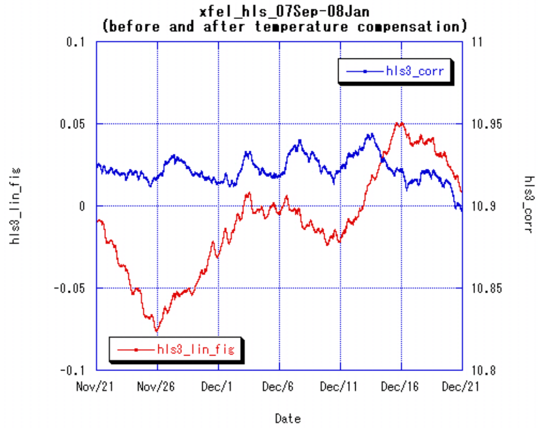

Fig.9 Example of HLS measurements before and after temperature compensation

is mainly correlative with the temperature of the pipe that buried in the soil, while, the temperature at sensor bottom makes daily modification. The temperature effect of the communication pipe is derived as a coefficient of -0.12mm/C. That is, water level becomes lower as the temperature at the pipe increases. It is because the expansion rate of polyethylene pipe is larger than that of water [1]. On the other hand, temperature at sensor bottom induces water level fluctuation for about 0.01mm/C.

Measurement is compensated with the temperature coefficients derived above. Figure 9 is an example of before and after compensating HLS measurements. After the compensation detail trend of the level change can be seen. It is implicit that the temperature induced measurement bias is well corrected.

About the long-term movement of the ground

Measurement data are normalized to 20 degree with the temperature coefficients derived and decomposed into long-term trend and short-term variation with a tidal analysis program BAYTAP-G [2]. Figure 10 shows the trends of level changes for the 5 monuments, taking hls-4

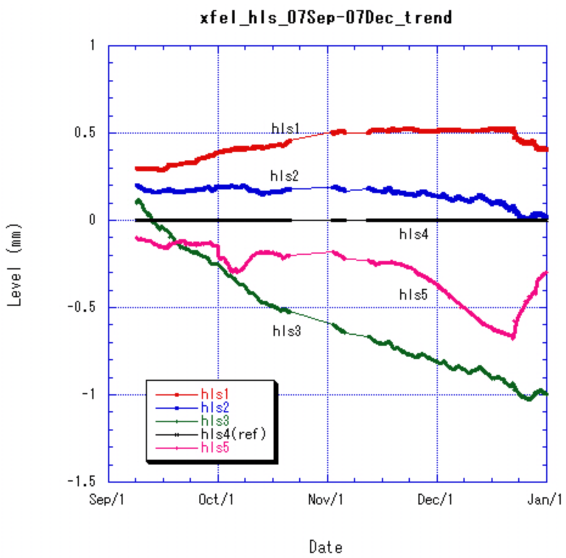

Fig.10 Trend of long-term level movement of the monuments

as the reference, because it seems relatively stable. There are no significant movements for hls-1, 2, or 4. While the monument hls-3 is subsiding continuously, where was a gully for the old ground. Subsidence speed is about 1mm/4months (3 mm per year). The movement at hls-5 from mid of November coincides with the progress of ground reinforcement work at the site.

About the short-term movement

Short-term variation of the monument is obtained by subtracting the component of long-term trend from the measurement. Excluding slow ground movement, the short-term includes the movements result from the earth tide, sunshine, rainfall or earthquake etc. Figure 11 shows the short-term variations of the monuments for one month. Obviously, the movements are mainly tidal components. Because of tidal effect, the ground moves on the tilt and the two ends of the HLS are moving in opposite direction. Maximum amplitude is 60μm in 400 meters (0.15μrad). The tidal component observed here is the height difference of the tides of the earth and the ocean, because

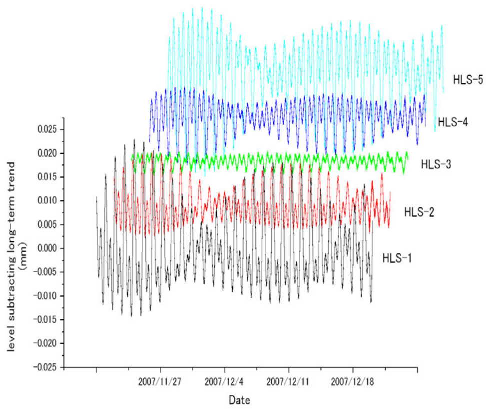

Fig.11 Variations of the short-term movements of the monuments

the sensor is fixed on the ground and measures water surface. Actual amplitude of the earth tide is about a half of the observed value of HLS.

To understand how much the 400 meters ground is distorted by the earth tide, relative movement of a monument with respect to the straight line that connecting the two ends are calculated.

Figure 12 is 24-hour relative movement of the monuments, taking two end monuments as references.

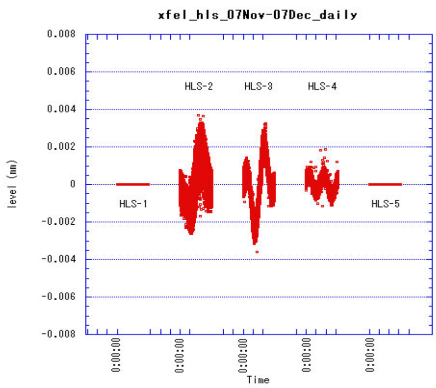

Fig.12 24-hour relative movements of monuments

Continuous data of one month are overlapped and plotted in one day's length. It can be seen that the relative movement is in regular and repeated every day, with some phase shift. This relative displacement should include the distortion of the geoid and the ground. Maximum displacement is ±3μm occurred in 2nd and 3rd monuments. It is very small that the relative movement between monuments caused by the earth tide seems to be negligible and the ground movement of the tilt could be treated as a hole in 400 meter range

About system's resolution

The observation for the relative movement of the middle (hls-3) with respect to the two ends for three consecutive days is shown in figure 13. The movement within sub-micron can be clearly seen. It is implicit the system's resolution for level measurement is less than one micrometer, better than we expected. The system therefore has an ability to measure not only long-term ground movement but also minute ground distortion for the length of 400 meters XFEL accelerator.

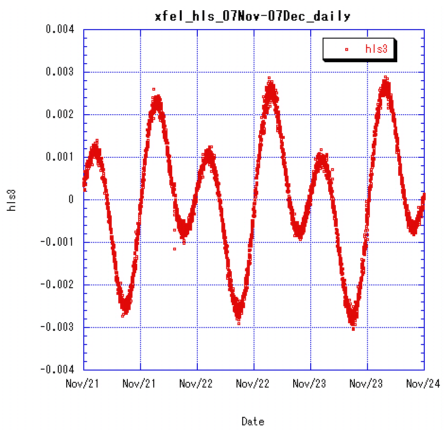

Fig.13 Relative movement of the middle monument for three consecutive days

CONCLUSION

A reference line of monuments is built at the SPring-8 site, to measure the ground movement at the XFEL site, and monitor the deformation of the XFEL buildings. At present, a four hundred meter HLS is made.

We adopted full-filled system and in the meanwhile made some compensative measures to reduce temperature effect. The HLS is built one meter beneath ground level and water tanks are used. Moreover, temperature probes are extended to inner soil and attached to the communication pipes for the temperature compensation of the measurement.

For the long-term movement of the ground, measurement observed a continuous subsidence of an unstable point, where was a gully for the old ground. Subsidence speed is about 1mm/4months. For the short-term movement, main component is the tides. Because of the tidal effect, the ground moves on the tilt, maximum amplitude is 60μm /400m (0.15μrad). The tilt could be treated as a hole for a 400 meter range. Earth tide induced distortion of a 400 meter straight line is observed. Relative movements between monuments are very small and less than ±3μm.

The underground HLS has a resolution less than one micrometer, is able to measure not only long-term ground movement but also minute ground distortion for the length of 400 meters XFEL accelerator.

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