Slow ground motion at the KEK-PS main ring tunnel

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SLAC
The KEK-PS complex comprises four accelerators: two 750-keV Cockcroft Walton pre-injectors, a 40-MeV injector linac, a 500-MeV booster synchrotron and a 12-GeV main ring. The slow extracted beams are served to two counter halls (north and east) by a half integer resonance, and the internal target has also served the secondary beam in the east counter hall. The long-base-line neutrino-oscillation experiment, K2K (KEK to Kamioka) has started from January 1999. In order to perform this experiment, new fast extraction system were constructed and the intensity upgrade studies have been continued. A neutrino beam line, extended from the north counter hall, comprises the straight and arc sections, a target station, a decay volume and a monitor pit.

Although magnet alignment is one of the key issues of the stable particle acceleration to reduce the closed orbit distortion, re-alignment works were carried out only several times and the correction were made only for the vertical direction of the main ring quadrupole magnets.
Neutrino Beam Line
(Under Construction)
Evidences of the slow ground motion in the KEK-PS tunnel

First evidence
During the re-alignment work (vertical only) performed in the summer shutdown, 1996, a significant unconformity of the magnet height occurred in the weekend. During weekend, it had been heavy rain.

Second evidence
Beam orbit fluctuation were recorded with the weather condition during PS operation from November 5 to 25, 1996. Figures can be seen in http://www-accps.kek.jp/Reports/SR/SR407/

Third evidence
Closed orbit before and after the 1998 long shut down for the preparation work of Neutrino experiment. All parameters are same as those before shutdown.

Fourth evidence
Re-alignment work performed in the summer shutdown, 2000. Benchmarks were stamped on the outside wall in the tunnel prior to alignment work. A significant displacement of the benchmark for one month between the end of August and the end of September was observed.

These are supposed that the heavy rain might correlate the floor motion in the main ring tunnel.
Third evidence

Closed Orbit before and after the 1998 long shut down. Even if, all parameters are same as those before shutdown. Closed orbit became three times than that of before.
Displacement of the benchmarks on the wall

{Left point (4-7B) is the hypothetical fixed point}
Although the lattice structure of the KEK-PS accelerator has a four-time symmetry, the floor in the main ring tunnel comprises eight separated blocks (named A1, A2, B1, B2, C1, C2, D1, and D2), and they are not symmetry. Around the beam injection area, the floor is divided into three plates as C2, D1 and D2. In order to know the floor level fluctuation, the tilt meters using accelerometer are set on the border of C2-D1 and D1-D2.
There are several remarkable facts.

1) In the middle of October 1997, floor level between C2 and D1 changed rapidly (in fifty hours) by about 0.15 mm.
2) Continuous variation of the C2-D1 difference, which increased gradually up to 0.35 mm for a few months. This movement turned its direction from the middle of January 1998. This floor difference causes a few millimeters (rms.) closed orbit distortion.
3) This movement turned its direction again from the beginning of August 1998.
4) The movement like this did not appear in the 1999.
5) One more remarks are that many seismic vibrations (spike-like fluctuation is observed. The level difference returned to the one before earthquake in the almost cases, however, the deviation remained after an earthquake in the rare cases.
6) The variation of D1-D2 is smaller than that of C2-D1 but these are correlation with each other.
The KEK-PS tunnel was based on the ground level and covered by the water-rich soil. We once considered that the groundwater caused the floor motion. The velocity of infiltration downward through the soil was found to be very slow. It takes typically several days for the water levels in the aquifer to change after rainfall. A tunnel of this type received the stress from the moisture contained in the soil bank.

Under collaboration research with Geological Survey of Japan, Time Domain Reflectmetry (TDR) probes to measure the moisture and Tensilemeters made by Porous Ceramics to measure the pressure, detector of the resistivity in the soil and a rain gauge are mounted in the soil bank. Two kind of TDRs, shallow (1.2m) and deep (3m), are buried at A, B, C.
North counter hall

East counter hall

Under ground water monitoring well

TDR, Tensimeter

Resistivity monitor
Contours of moisture in the soil bank at October 13, 1998, just before rainfall. It was rain of 25mm at October 21. These suggest that the water in the top of bank does not infiltrate to the bottom by the obstacle of the confined air above tunnel and has been staying for a long days and has continued to press the tunnel through this air.

Measurement results of the resistivity in the soil consistent with the TDR measurement.
Contours of moisture (A-C Line) in the soil bank for October 13 – 26, 1998, Rainfall of 25mm at October 21

TD R setting depth
Shallow Deep
A 0~1.2m 2~5m
B 0~1.2m 1~4m
C 0~1.2m 2~5m

98.10.13
98.10.26
98.10.22
98.10.29
98.10.23
98.9.16
Very wet before one month
According to this speculation, the air exhaust pipes to reduce air pressure were buried horizontally. Measurement at September 1999 shows this effect. It has not been rain for a while and was rain of 27.5mm at September 21 and 12.5mm at September 22. On September 20, the contours of moisture in the soil bank are almost same as that of October 13, 1998. Even if just after rain, moisture of soil was only 40% and dried to that of before rain after only five days. No large deviation in December 1999 can be explained by the effect of these air exhaust pipes.
Contours of moisture (A-C Line) in the soil bank for September 20 – 27, 1999, Rainfall of 27.5mm and 12.5mm at September 21 and 22, respectively

Set of the air exhaust pipes

<table>
<thead>
<tr>
<th>T D R setting depth</th>
<th>Shallow</th>
<th>Deep</th>
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<tbody>
<tr>
<td>A</td>
<td>0~1.2m</td>
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<td>B</td>
<td>0~1.2m</td>
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Conclusion

Continuous patient measurement is essential to confirm that the speculation is true or not.

A long-term measurement of floor level is necessary to confirm the long-range displacement and its correlation to the rainfall and underground water. Anyway, an observation of the movement in a few days with the range of about 0.15 mm by tilt meter. This fact suggests that the movement of the order of 1 mm could occur rapidly.

At this time, only two tilt meters were set up. If tilt meters will be set up at all the borders between plates, the floor level fluctuation in the PS main ring tunnel would become to clear.

In the summer of 2000, we experienced frequent thunder and lightning. Not a few equipment is damaged by thunderstorm and those detectors on the soil bank were damaged either. Then, we have no systematic data of the underground water level, measurement of resistivity, TDR and Tensilemeter. Data of tilt meter is under analysis. Further, an analysis of the re-alignment work is also under processing. We expect the result.