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THE DESIGN AND PROTOTYPE TEST FOR THE TUNNEL FOUNDATION OF HIGH ENERGY PHOTON SOURCE

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Abstract

High Energy Photon Source (HEPS) is being built in China with challenging beam stability requirements. To fulfil the 25 nm ground motion restriction on the storage ring tunnel slab, two prototype slabs with different design schemes were constructed on the HEPS site. The first scheme adopted a 1 m reinforced concrete with replacement layer of a 1 m sand & stone underneath. The second scheme employed an extra 5 m grouting layer below the previously mentioned two layers. A series of tests had been carried out. The prototype slab with grouting layer is testified to have comparable vibration level with the bare ground, which is under 25 nm without traffic inside the HEPS campus, while the vibration level is amplified a lot on the other prototype slab. However, it is hard to make the grouting layer homogeneously under the kilometre-scale tunnel and besides the cost is unacceptable for 5 m grouting with such a large scale. The finalized design is fixed to be a 1 m reinforced concrete slab and 3 m replacement layer underneath using plain concrete. In this paper, the details of the prototype slab test results will be presented.

INTRODUCTION

Currently, the low emittance storage ring has considered being future development direction of the photo sources. However, with the decreasing of the designed emittance of the ring, the problems caused by the ambient ground motion have been increasingly highlighted. High Energy Photon Source (HEPS) is a 6 GeV, 1.3 km, ultralow-emittance storage ring light source to be built in Beijing, China [1]. The designed natural emittance is about 35 pm [2]. To ensure the stability of the beam on experimental station, the RMS displacement integration of vibrations on the slab has to be kept smaller than 25 nm over frequency range of 1 Hz up to 100 Hz [3]. In order to fulfil this requirement, three more specifications are set up according to the ground motion level of HEPS site:

1) Ambient motions on the slab caused by internal and external vibration sources have to be smaller than 1 nm in all three directions;
2) No vibration amplification by the slab of the storage ring (RMS integral over frequency of 1-100Hz);
3) No vibration amplification by the pedestal-girder-magnet assembling.

The first one will be realized by setting regulation plan to the transportation inside the HEPS campus and taking damping measures for the vibration utilities. And the Egan frequency of the pedestal-girder-magnet assembling is specified to be not smaller than 54 Hz for achieving amplification factor closing to one [3]. A well designed and made slab has no vibration magnification to the ground motions [4]. To construct such a slab and finalize the slab design, two prototype slabs with different design schemes were constructed on the HEPS site. The test results will be introduced in this paper.

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PROTOTYPE SLABS

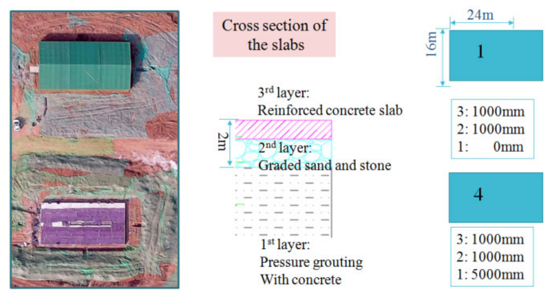

Figure 1: The schematic design of the two prototype slabs.

Figure 2: The prototype #4 slab: after grouting.

As shown in Fig. 1, the dimension of the prototype slab is 16×24 m. To construct slab #1, the soil from 2 m underground to the top were taken out and backfilled with one meter of "graded sand and stone" and one meter of " reinforced concrete slab". For the 2th slab (slab #4), there is an extra grouting layer from -2 m (underground) to -7m.

For constructing the grouting layer, as shown in Fig. 2, steel pipes (about 8 m long) were inserted in the ground using boring machine. The pipes are placed at the intervals of 1 m (0.8 m for the outermost two rows). There are some small holes regularly distributed on the pipe from depth of -2 m to -7 m. Mixture of cement and water were grouted through the pipe for reinforcement of the underground layer (-2 m to -7 m). The maintenance time for the grouting layer is ~28 days, all the other steps are the same with slab #1 hereafter.

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Vibration Response on Prototype Slab #1

Figure 3: Graded sand and stone layer of slab #1.

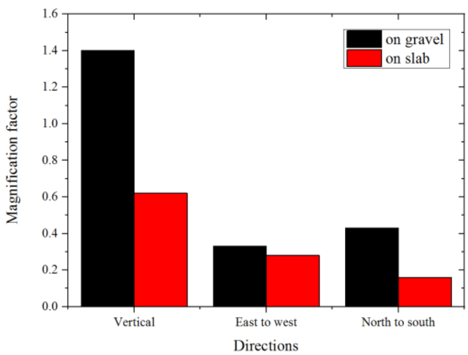

Figure 4: Vibration magnification factor of each layer for #1 slab.

During construction of slab #1, to evaluate the damping effect of "graded sand and stone" layer (the 2nd layer) and the "reinforced concrete slab" (the 3rd layer), an excavator was used to generate noises by hitting the ground as shown in Fig. 3. Vibration data was taken before and after pavement of each layer. The ratio between the noise level on each layer to the noise level 2 m underground gives the magnification factor. As shown in Fig. 4, the magnification factor of the 2nd layer (black bar) is bigger than one for vertical plane and smaller than one for the other two planes. While for the 3rd layer, the magnification factor (red bar) is smaller than one for all three planes. We can conclude that the performance of the 3rd layer is good, but the 2nd layer is not as good as expected. Figure 3 shows what the 2nd layer looks like. We suspect that the bad performance of the 2nd layer might be caused by not even enough stones, and not compact enough pavement.

Vibration Response on Prototype Slab #4

Slab #4 has an extra grouting layer of 5 m. After finished grouting and taking out soils with thickness of 2 m, vibration data were taken in the #4 pit (-2 m: on the grouting layer) and compared with the noise level on slab #1. A vibration exciter placed in middle of the two prototype slab positions, was used for generating 1 Hz~100 Hz vibrations. Besides the sensors on slab #1 and on grouting layer of #4 pit, an extra one with the same distance to the vibration exciter is placed on the ground as a reference. As shown in Figs. 5 and 6, the noise level on grouting layer (before pavement of the other two layers on top) is already smaller than slab #1 (both at 3 m away from the prototype margin).

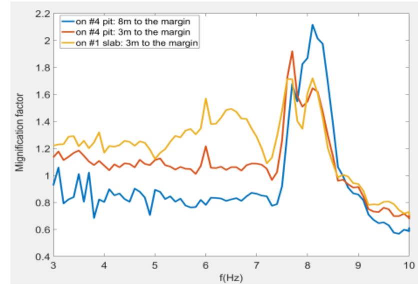

Figure 5: Magnification factor for slab #1 and 4# pit with grouting layer for frequency range of 1-10Hz.

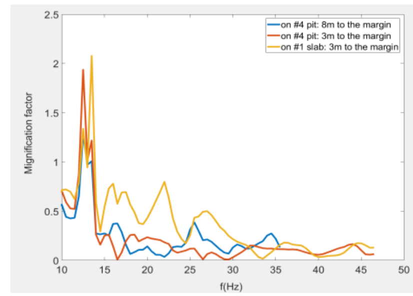

Figure 6: Magnification factor for slab #1 and 4# pit with grouting layer for frequency range of 10-50Hz.

And the further the sensor from the vibration source, the smaller the noise level will be. For the noise level 8 meters away from the margin of grouting layer, the magnification factor is smaller than one for 1 Hz~50 Hz, except 7-9 Hz and 10-15 Hz. The ground is sensitive to the vibrations of these frequencies, and grouting could not solve this problem either.

After finished the pavement of the other two layers. Long time vibration monitoring on the two prototype slabs were carried out for about one week.

Long-Time Motion Monitoring on Prototype Slabs & on Ground

As shown in Fig. 7, vibrations on four positions were monitored, two seismographs on two prototype slabs and one sensor on ground close to slab #4. The vibration source is the traffic noises on a municipal road (labeled in Fig. 7 as blue arrows, closed now) of HEPS site, which has proximately same distance to the above mentioned three sensors. As the prototypes are located at the position where the outdoor cryogenic storage tank farm is, which is about 100 m away from the storage ring. One extra sensor is placed on the ground of the storage ring close by. As shown in Fig. 8, the measurement results of two sensors on ground show clearly day and night shift. Horizontal vibrations are bigger than vertical directions. During night, the motion on ground is about 4 nm and 10 nm vertical and horizontal respectively. During day time, it is about 10 and 20 nm. Most of the time, the green field vibration is smaller than 25 nm, the sparks might be caused by cars with higher speed or trucks with heavier load, which is under control. For the vibrations on the slabs, as shown in Fig. 9, during the weekend, when there is not so much traffic, the vibration level is almost the same on the two prototype slabs & the ground. During the weekdays, when the traffic is

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heavier, the vibration is amplified a lot on slab #1, while the prototype slab #4 with extra 5 m grouting layer has comparable vibration level with green field. Although the performance of the grouting scheme can fulfill the requirement pretty well, it is not adopted for the foundation design finally. As it is hard to make the grouting layer homogeneously under the kilometer-scale tunnel and besides the cost is unacceptable for 5 m grouting layer with such a large scale too. The finalized foundation design for the storage ring and experimental hall is fixed to be a 1 m reinforced concrete slab & 3 m replacement layer underneath using plain concrete which is verified by simulation to be having equivalent effect as the grouting scheme.

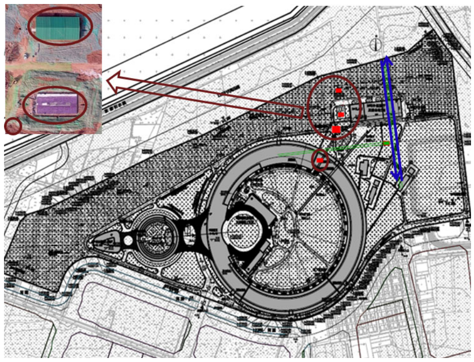

Figure 7: Long-time motion monitoring on prototype slabs & on ground: the four red squares are four monitor positions, the street where the blue arrows are is a municipal road inside the HEPS campus (it is closed now).

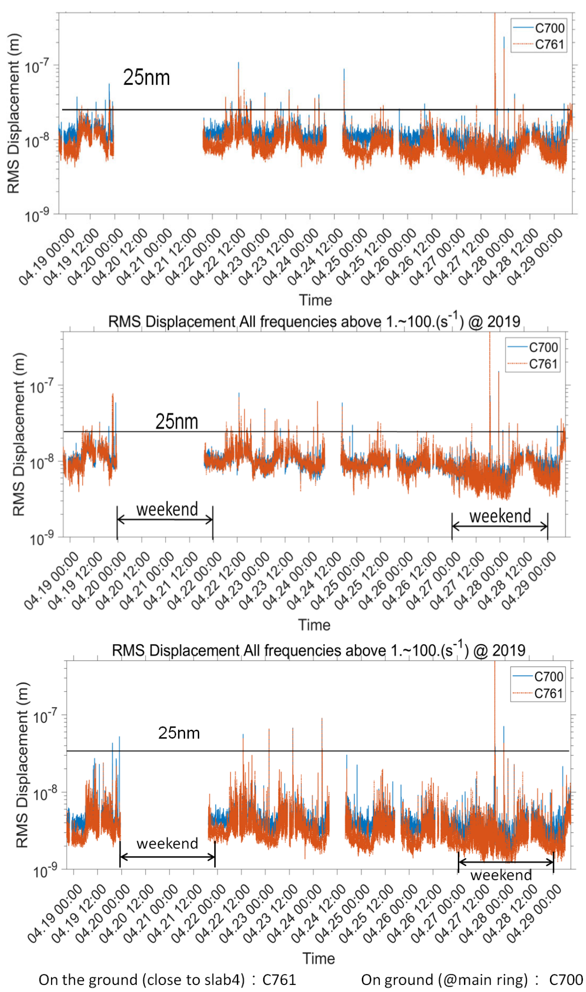

Figure 8: The red curve (C761) is the vibration RMS displacement on the ground nearby slab #4, north & south (above figure), east & west (middle figure) and vertical direction (the figure below); the blue curve (C700) is RMS displacement on ground of storage ring for the three directions respectively.

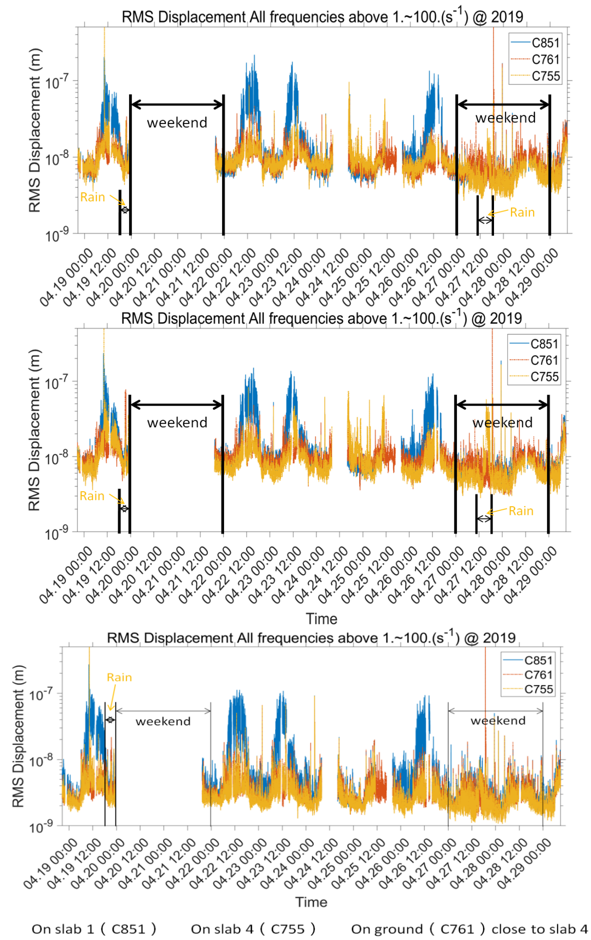

Figure 9: The red curve (C761) is vibration RMS displacement on ground close to slab #4, the yellow curve (C755) is vibration RMS displacement on slab #4, and the blue curve is the measurement data on slab #1.

CONCLUSION

In order to define the tunnel foundation of HEPS. Two prototypes of different design were constructed. The one with extra grouting layer has comparable noise with bare ground. Considering the cost and construction difficulty, the finalized design is fixed to be a 1 m reinforced concrete slab & 3 m replacement layer underneath using plain concrete which is verified by finite element analysis to be having equivalent effect as the grouting scheme.

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