Construction Method of Super Flat Concrete Slab using High Precision Height Measurement

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Abstract -

The new Hachinohe indoor skating rink required an extremely flat concrete slab. ±2mm precision concrete surface was expected across 6,350 m² concrete slab. It is impossible to construct such a large super flat slab with a conventional construction method to maintain the height of the concrete surface at intervals of few meters using human hands and eyes. Therefore, we have developed a construction method using high precision height measurement which maintains the height of the concrete surface in the levelling and the finishing processes with high density and precision.

In the levelling process, a 18m long truss screed was used. Such a long truss screed is easily deformed and the deformation of the truss screed during the process directly leads to the deterioration of surface accuracy. Therefore, we developed a mechanism to measure and correct the deformation of the truss screed with high accuracy.

In the finishing process we precisely scanned the levelled concrete surface with a 3D laser scanner. An unevenness distribution map was calculated from the scanned point-cloud data and projected onto the concrete surface using a projector to remove the concrete on the convex part.

Finally, all the finished concrete surface was measured with a 3D laser scanner and confirmed that it had extremely high flatness.

Keywords -

Flatness of Concrete; 3D Laser Scanner; Projection Mapping; Truss Screed

1 Introduction

The Hachinohe Nagene indoor speed skating oval rink, equipped with 400m double tracks, is the third indoor speed skating facility that is in conformity with international standards in Japan. The construction of this skating rink involved various efforts to build a high-quality, indoor skating rink meeting international standards, one of which is the construction of the concrete slab beneath the ice.

The cross-sectional structure of the skating rink is shown in Figure 1. Refrigerate pipes were installed in the ice-making concrete slab, and the ice layer will be formed over the slab via cooling. The surface precision of the ice-making concrete slab affects the thickness of the ice layer, thereby affecting the hardness of the ice layer. Building a high-quality skating rink with an even level of ice layer requires ice-making concrete slab with high surface precision; in this construction, the goal surface precision was set within ±2mm.

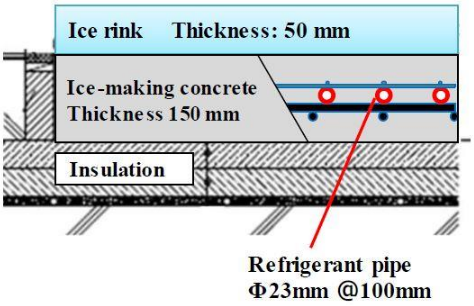

Figure 1. The cross-sectional structure of the rink

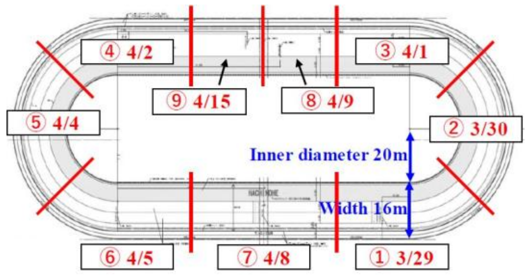

Figure 2. Construction sections of the ice-making concrete slab

The ice-making concrete slab is comprised of a straight section with a width and length of 16m and 110m, respectively, and a curved part with inner and outer diameters of 20m and 30m, respectively. The total area of the skating rink is about 6,350 m².

The conventional construction method of concrete

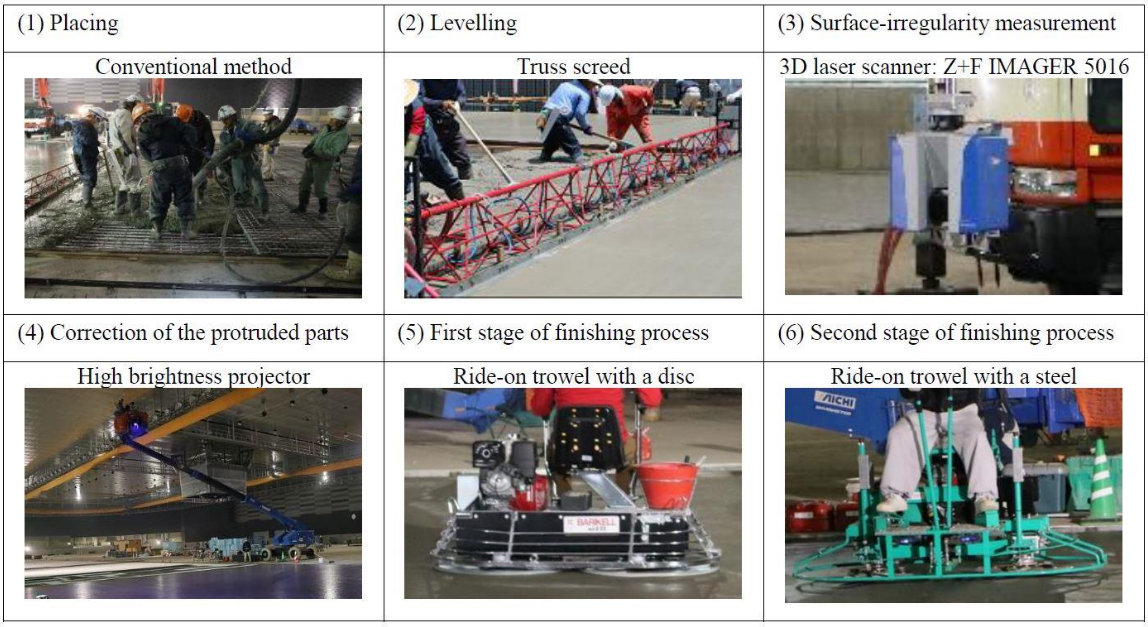

Figure 3. Construction processes of concrete slab

slab involves human hands and eyes to maintain the height of the concrete surface at intervals of few meters, thereby rendering the ±2mm precision across this large area practically inconceivable. Therefore, we assumed a mechanized construction method that maintains the surface height in the levelling and finishing processes with high density and precision. As shown in Figure2, the 400m circumference was divided into nine sections, and each section was constructed within one day. Figure 3 shows the construction flow and the machines used in the ice-making concrete slab. After the hardening of the concrete, 3D Laser Scanner was used to evaluate the flatness [1],[2].

2 Construction of Super Flat Concrete Slab

We have developed a construction method using high precision height measurement which maintains the height of the concrete surface in the levelling and the finishing processes with high density and precision.

2.1 Levelling Process

A truss screed, which was composed of an iron truss frame and a blade, was used to level the concrete. Units, each with a width of 3.5m, can be linked to make the maximum width of 20m. The portion that meets the concrete is an L-shaped blade with multiple oscillators driven by compressed air. Both ends of the truss screed are placed on rails installed outside the cast concrete area., and the concrete surface is levelled by moving the truss screed along these rails while providing vibration. Truss screed is deformed because of the loosening of the joints which is caused by vibration and of the force from the placed concrete. Because the shape of the truss screed directly affects the surface precision of the ice-making concrete slab, we attempted to improve the surface precision during the levelling process using a high-precision level monitoring system for managing the levelling. The method of level monitoring is described below.

At each joint, we measured the top height of the blade and adjusted it by tightening the joint every 2 m in the driving direction. As shown in Figure 4, we installed rotating laser receivers at five locations on the truss screed and used a level monitoring system which displayed the heights with 0.1mm resolution on a tablet PC in real-time. Using a rotating laser level, we can detect relative changes in height with high accuracy and in real time, but we cannot measure absolute height accurately. On the other hand, using a digital level, we cannot measure the height change in real time, but can measure the absolute height accurately. Therefore, we decided to measure the absolute height at each location using a digital level and monitor the changes from the measured values with a monitoring system using a rotation laser level. By using this system and adjusting the height of the blade to within ±1mm from the standard level, a precise levelling process could be performed.

Figure 4. Monitoring for the levelling blade using a display system for level change

2.2 Measurement of Surface Irregularities immediately after Levelling

We used a 3D laser scanner to measure the surface irregularities immediately after levelling. Figure 5 is a picture of the situation of this measurement. The concrete surface, immediately after levelling, has a gloss that bends the laser light, so a small incident angle to the measured surface is preferred. Therefore, the scanner was attached at a boom of a crawler crane and scanned the concrete surface from a height of approximately 9 m. Each measurement was performed over a 16 m × 12.5 m area, 1/4 of the total placement area for a day, and it took 43 seconds for an irregularity measurement with a maximum 10mm pitch. Using this measurement method, the boom oscillation in the crawler crane and the boom drop were suspected to affect the measurement of surface irregularities. Therefore, we obtained the data on the boom oscillation and the boom drop in advance and verified that they would not affect the measurement results if the time of scanning was 43 seconds.

Figure 6 shows an example of point-cloud data for the concrete surface obtained by the 3D laser scanner. The point-cloud data are obtained in the coordinate system of the 3D laser scanner. Hence, if the coordinate axis in the height direction is not vertical, we cannot accurately evaluate the irregularities on the concrete surface against the design height. Thus, we evaluated the surface irregularities using the following method.

1) We placed four 700mm × 700mm reference plates around the target concrete surface.
2) The surface of each reference plate was levelled with a high-precision inclinometer, and the heights of the four reference plates were adjusted to be the same.
3) From point-cloud data obtained by the 3D laser scanner, we extracted the clouds corresponding to the reference plates and from that clouds, computed one virtual reference plane.
4) As shown in Figure 7, the reference surface is horizontal and its height (H) is known, so it was used to calculate the irregularity (h) compared to the design height based on the distance of each point cloud (d) from the virtual reference plane.

Figure 5. 3D scanning a concrete just after levelling process

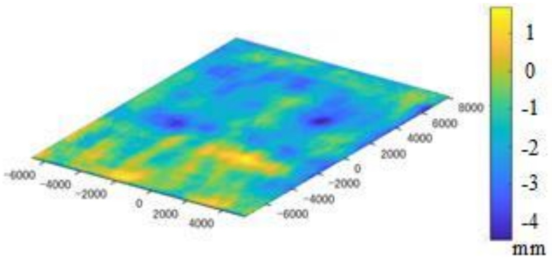

Figure 6. Example of a point-cloud data

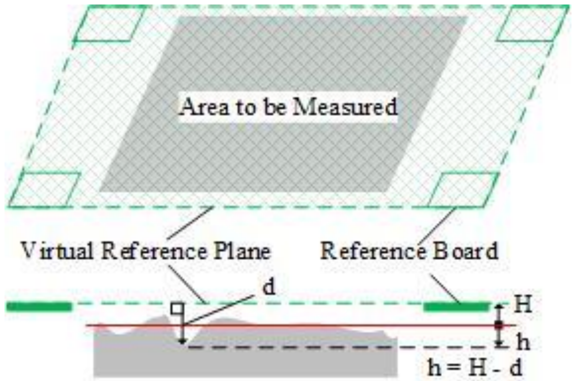

Figure 7. Calculate irregularity of surface

2.3 Correction of Irregular Portions

To further improve the surface precision of the concrete, which was levelled by the truss screed, we conducted a process of scraping the protruded concrete. When the craftsman with the plasterer's boots can stand on the concrete without deforming the concrete surface, the correction process can be started. From the previous setting test, we found that this condition was met when the penetration-resistance value exceeded 0.5 N/mm^2, thus, we began the correction process when the penetration-resistance value became 0.5 N/mm^2.

In the point cloud data of surface unevenness acquired after leveling, the part where the surface height is higher than the design height (= +0 mm) was set as a correction target. Moreover, we generated a 2D image (image for correction) of the point-cloud data with the target and other areas indicated by red and blue colors, respectively. Figure 8 shows an example of such a correction image. The scraping depth on the concrete was set 2 mm from the surface. Furthermore, to allow the operators to accurately view the operation areas, we directly projected and visualized the correction image on the concrete surface. For the projection, a large projector was installed on an elevating work platform approximately 10 m above the ground. Figure 9 shows a picture of the correction process. The concrete surface became rough after the scraping. Hence, a disc was installed on a trowel and the surface of corrected portions were smoothed.

Figure 10 shows an example of the comparison between the surface irregularities measured immediately after levelling and after the finishing process. The standard deviation of the surface irregularities decreased

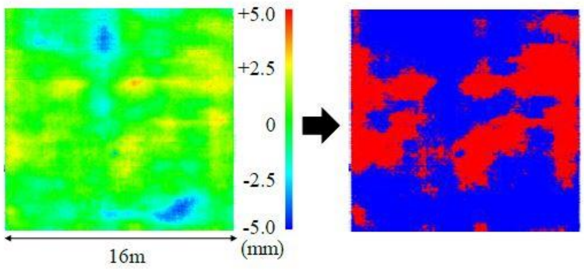

Figure 8. Example of a correction image

Figure 9. Projection of the correction image

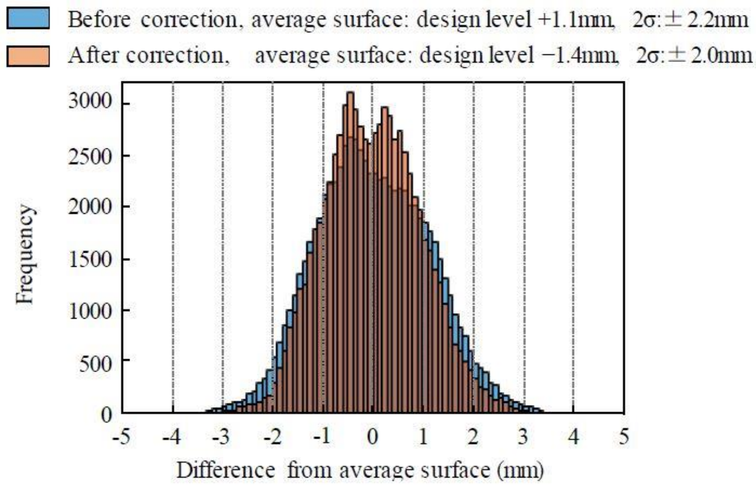

Figure 10. Comparison of the surface irregularities after the levelling and after the correction process

from 1.1 to 1.0 mm, and the frequency of the mean value ±1 mm increased by 14.4%, indicating an improvement of the surface precision. Here the median value is not the design height but the average height of the concrete surface. The average height of the concrete surface shifted from +1.1 to −1.4 mm, because of the rise in bleeding water and the compaction on the surface from the finishing process.

3 Flatness of the Completed Ice-Rink

3.1 Measurement using 3D Laser Scanner

In general, the 3DLS is not able to be set strictly horizontal and the level of the scanner is unknown. The scanner coordinate system is based on different height and attitude from a base coordinate system. To measure the height of the concrete slab, we must match the height and attitude between the scanner coordinate system and the base coordinate system. Around the scanning area, we put three reference boards and measure each height of the boards. We translate the scanned point-cloud in order to match each height of levelled boards in the point-cloud to the measured height of them in the real world. The detailed procedure is shown below.

1) Putting 3 boards, which size is 700mm x 700mm, around the scanning area. Adjusting lengths of the three support legs to level the boards.
2) Using a digital level, measuring Z_{DL1}, Z_{DL2} and Z_{DL3} which are the board surface heights.
3) Using 3DLS, scanning the area which includes the 3 reference boards.
4) From the scanned point-cloud, detecting Z_{ave1}, Z_{ave2} and Z_{ave3} which are heights of center of the 3 reference boards.
5) Deriving a rigid body translation T from an equation below.

$$\begin{pmatrix} x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \\ z_{DL1} & z_{DL2} & z_{DL3} \end{pmatrix} = T \begin{pmatrix} x_1 & x_2 & x_3 \\ y_1 & y_2 & y_3 \\ z_{ave1} & z_{ave2} & z_{ave3} \end{pmatrix} \quad (1)$$

x_i, y_i, i = 1, 2, 3 are x-y positions of each center of the

Figure 11. Conventional measurement method

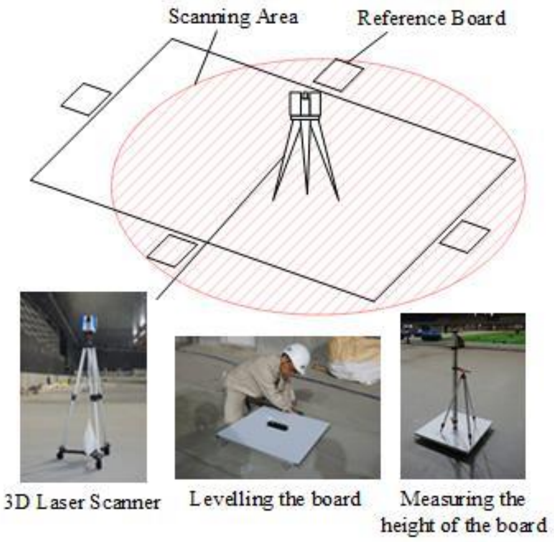

Figure 12. Proposed measurement method

reference boards in the scanner coordinate system.

6) Translating the scanned point-cloud with the rigid body translation T and getting a point-cloud in which, each height of board equals the height measured using a digital level.

3.2 Confirming Measurement Method

In order to confirm our proposed method, we measured a part of the rink (14m x 15m) using the proposed measurement method and a conventional measurement method. And we compared the data which was acquired with the two methods.

3.2.1 Conventional measurement method

We used a digital level for conventional measurement method. At first, we draw measured points on the floor in a grid of 0.5m. We divided the measurement area (14m x 15m) into 3 parts. 6 people, 3 pairs, measured each part. In the pair, one set a staff and the other collimated it and recorded the measured height (Figure 11). It took more than 4 hours to measure 899 points.

3.2.2 Proposed measurement method

3 people worked in the proposed measurement method. We set 4 reference boards and measured the height of each board. Since the circle with a radius of about 1.0 m just below the scanner cannot be scanned, we scanned the target area at two different points. It took less than 10 minutes and measured about 10,000 points height in grid of less than 10mm.

3.2.3 Comparing the two measured data

Figure 13 shows the measurement result using conventional method and proposed method. Visualization processing was performed so that irregularities with 100 mm grid spacing were displayed for comparison. According to this figure, the height distributions in each calculation result are almost the same in two dimensions. The height distribution is shown as a histogram in figure 14. Both have same standard deviations of 1mm. Although the number of samples is different, the height distribution tendencies are the same. Therefore, the measurement results of the proposed method are highly reliable.

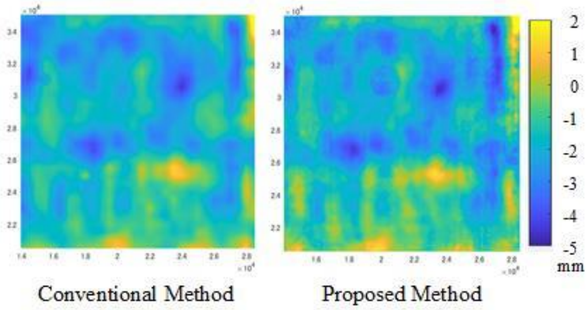

Figure 13. Comparison of two methods

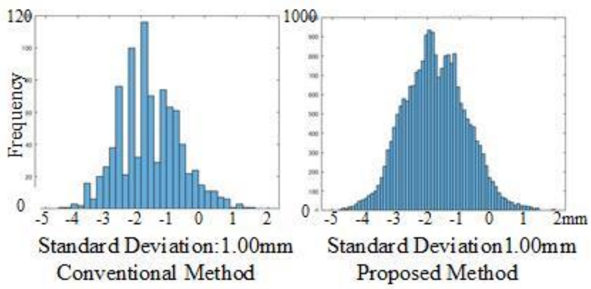

Figure 14. Comparison of two methods

3.3 Measurement Result of the Ice-Rink

Figure 15 shows that the ice-making concrete slab divided into 84 sections and the 3D laser scanner set at the centre of each section. Figures 16 and 17 show the measurement results. The standard deviation of the height is 1.22 mm, and 90.3% of the whole area is within ±2-mm precision. The curved portions in sections tend to be low. The reason is considered that the operation of the truss screed is difficult compared to the straight part of the rink owing to the difference in speed between the inner and outer portions.

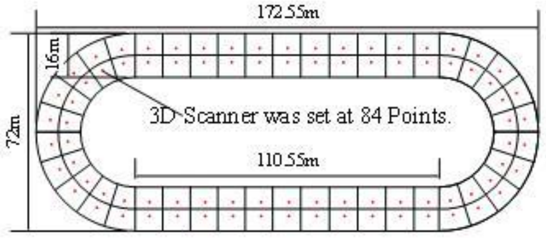

Figure 15. Scanned area was divided into 84 parts.

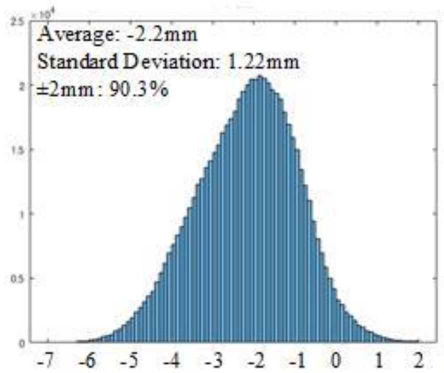

Figure 16. Height Deviation of the ice-rink

4 Conclusion

For the construction of super flat concrete slabs using a truss screed, we developed a method for obtaining the real-time level of the truss screed and achieved high precision levelling. After levelling, we measured the surface irregularities using the 3D laser scanner and applied the results to correct the protruding portions visualized with a large projector, thereby improving the surface precision of the concrete. Using the above methods, we achieved ±2mm precision for 90.3% of the entire area of approximately 6,350 m^2.

References

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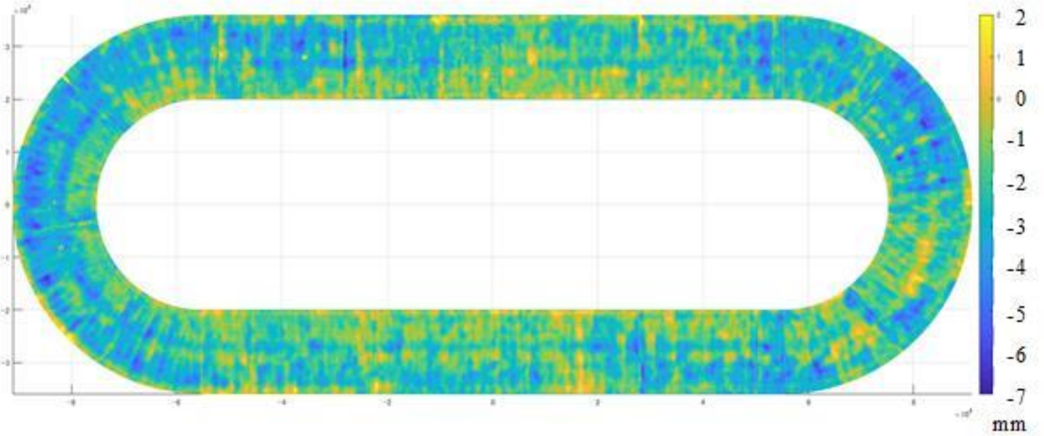

Figure 17. Height Map of the ice-rink