R&D for expanding application of a 3D concrete printing to construction

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Introduction

The number of construction projects fabricated by 3D printing with cementitious materials, hereinafter referred to as 3DCP, has surged across the world. As for Taisei Corporation, it began to develop suitable materials and mixtures for 3DCP in 2015 and has made progress in the development of hard devices, software, and construction methods and examined the qualities of members manufactured by 3DCP. A few of our achievements have been presented in international technical conferences such as Digital Concrete organized by RILEM since 2018.

The recent R&D efforts, which Taisei Corporation considers as promising technologies for social implementation, are introduced as follows in this paper.

R&D efforts to explore further 3DCP applications

1) RC strut of roof with multi functions brought by 3DCP

Photo 1 is the RC strut of roof with the outer embedded formworks prefabricated by 3DCP where the multi functions providing lighting, drainage and structural intensity are inherent in the body.

The structural part inside the outer formworks consists of rebars and cast concrete in a way similar to a conventional structure.

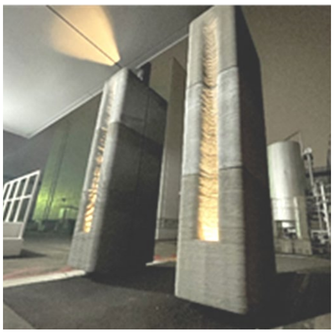

Photo 1: RC strut of roof with multi functions

2) Development of eco-friendly substitute used for 3DCP

The mixture ordinarily used for 3DCP contains a high volume of cement to secure the buildability, resulting in higher CO_2 emission in the production phase of constitutive raw materials than that of conventional mortar or concrete. Taking this into consideration, a novel mixture mainly composed of ground granulated blast furnace slag (GGBS) was developed for 3DCP. The mixture includes no volume of cement. In addition, when a newly developed substitute produced by converting collected

CO_2 into calcium carbonate is added to the novel mixture, the CO_2 emission becomes negative in the total amount. The eco-friendly bench fabricated by 3DCP with this mixture is shown in Photo 2.

Photo 2: Eco-friendly bench fabricated by 3DCP with carbon-negative substitute

3) Pedestrian bridge utilizing topology optimization analysis and 3DCP

Photo 3 shows the prestressed pedestrian bridge which is designed thorough topology optimization analysis and fabricated by 3DCP. The bridge girder consists of 44 segments along the longitudinal direction. After all the segments are mutually connected with epoxy-resin agent, PC steel bars are inserted into the pre-penetrated holes in the cross-section of each segment and the prestressed forces are added to the bars to unify the girder. The girder weight of the optimized shape becomes one fourth as much as the original shape.

In the verification study on the girder through in-situ bending tests, the deformation values during the tests provide good agreement with the FEM prediction. As a result, the bridge girder is demonstrated to be safe for operation and behaves as an elastic unit under crowded loading.

Photo 3: Pedestrian bridge utilizing topology optimization analysis and 3DCP

4) Large pier with an outer shell formed by 3DCP including short fibers

Figure 1 shows the structural drawing of the large pier which supports the bridge girder described above. The manufacturing procedure consists of the following three steps; an outer shell to be formed by 3DCP including high volume of short fibers, placement of pre-crossed rebars as a unit into the shell and inner filling with self-compacting concrete.

The relationship between the horizontal loading force and its displacement on the 3DCP pier (or the conventional pier) is shown in Figure 2. It is suggested that the uniaxial distribution of short fibers in the outer shell along the 3DCP extrusion process enhances the reinforcement for shear force and the confining effect of cover concrete, producing higher ductility than the conventional one.

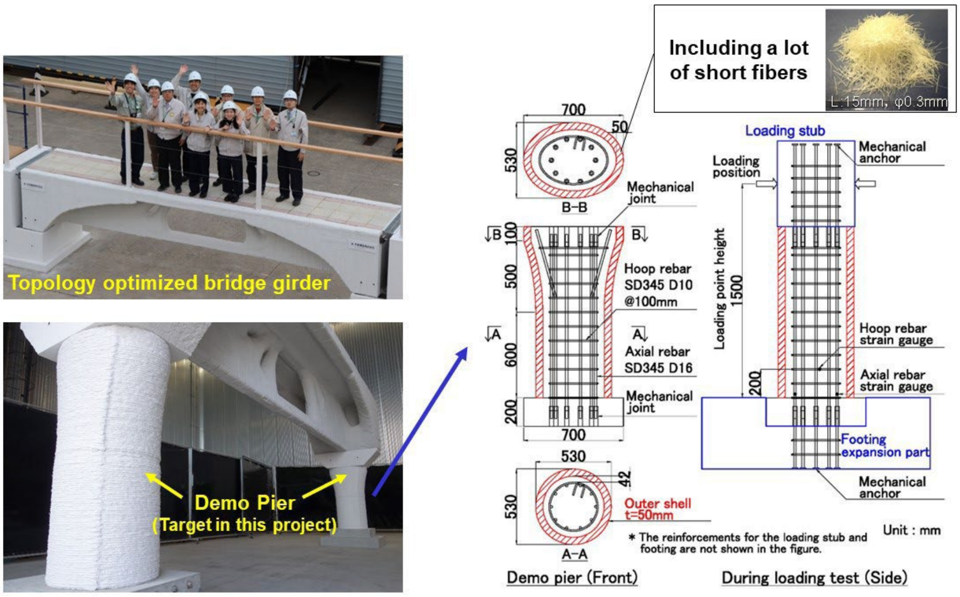

Figure 1: Structural drawing of the 3DCP pier

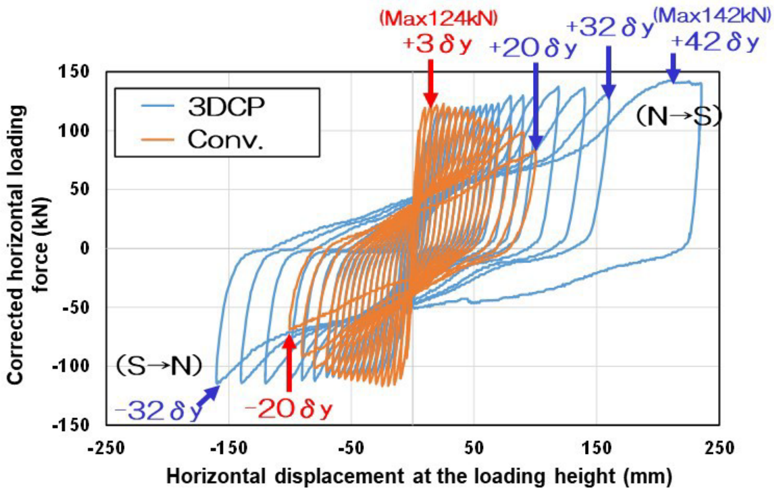

Figure 2: Relationship between the horizontal loading force and its displacement

5) 3DCP Operating algorithm applicable to a curved surface with large roughness

The operating algorithm in which a printing path is generated based on ground surface geometry obtained by 3D scanning and controls the movement of the nozzle head is newly developed. This enables 3DCP to be applied to arbitrary ground surfaces even if these surfaces have large roughness. In other words, direct 3DCP along local geometry can be implemented. The accurate printing on the vicious quasi ground surface is demonstrated in Photo 4.

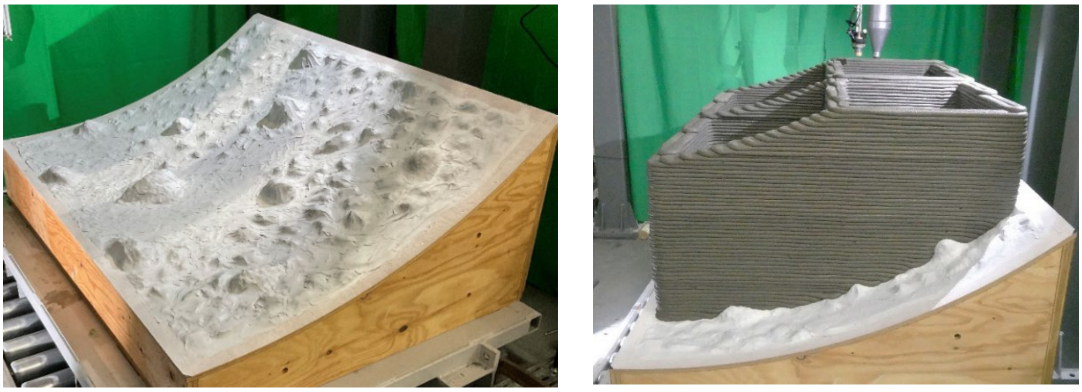

Photo 4: Accurate printing on a curved surface with large roughness

6) 3DCP technique to build a wider wall structure continuously and approach to pre-assembled rebars as much as possible.

A 3DCP technique that enables a robotic arm on a slider to build a wall structure with wider length while moving continuously is developed. If the length of the slider is extended, it can be applied to a larger and larger structure. Another feature is that this technique can reduce the width of cover concrete as much as possible, taking advantage of approaching the nozzle head to the pre-assembled rebars with a diagonal angle. It leads to cost savings due to the completion of a structure with a proper cross-section without extra cover concrete. These features are shown in Photo 5.

Photo 5: 3DCP technique with a robotic arm on a slider

Conclusion

The recent R&D efforts in Taisei Corporation are presented in this paper. Basic technological issues have been addressed greatly and the variations of materials and construction methods of 3DCP have been expanded until now. It will bring wider solutions to 3DCP applications, considering strict requirements given in construction. We are especially engaged in investigations of structural performance and durability of laminated structures with 3DCP. Furthermore, some studies on productivity, safety, cost/labor efficiency, and a smaller carbon footprint expected with 3DCP will be conducted positively.