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Development of Operation Technology and Two-Sided Multi-Point Press Equipment for Improving Accuracy of FCP

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Abstract
The ratio of free-form architectural design has been increasing recently. However, the current technology for the implementation of free-form buildings is very insufficient. In this study, the Two-sided Multi-Point press equipment, a FCP(free-form Concrete Panel) production equipment, is being developed to develop Free-form building technology. Two-sided multi-point press equipment is the equipment being developed in this study that implements the FCP's upper and lower foam. In this study, FCP is manufactured through this equipment and the operation technology of the equipment is developed to improve the accuracy of FCP. The two-sided multi-point press equipment developed in this study had several problems in implementing FCP and was studied to address them. Firstly, FCP's top and bottom mould, which is implemented as a two-sided multi-point press equipment, is implemented by the combination of Rod and Silicon Rubber, where there are problems with joining. There is also the problem that Silicon Rubber is a resilient material and cannot fully implement FCP. Secondly, FCP must have a constant thickness value for each segment, which requires a large amount of accumulated data collection. In this study, we conducted a study to maintain a certain thickness of FCP produced using development equipment. As a result of the study, the study proposed a new approach to data collection that was not previously available to maintain a constant thickness for FCP. If follow-up research is carried out based on the proposal, it will be able to be used as basic research material to maintain FCP thickness. It is also believed to be available as a basic research material for automated production of FCP. The technology to keep FCP thickness constant by segment is very complex and difficult, but the new research method proposed in this study will be used as a basic research material to address this.

Keywords: *FCP(Free-form Concrete Panel), Free-form Building, Free-form Construction, Multi-point Press, CNC Machine.*

1. Introduction

With the development of computer technology, it is possible to design free-form building more freely compared to the past and the number of free-form buildings is increasing. Free-form buildings are more beautiful compared to the free-form buildings. it is also possible to boast local construction technology by building free-form buildings, so each country is building free-form buildings as landmarks[1]. However, There are many problems in the production technology of FCP(Free-form Concrete Panel), because free-form buildings have geometric shapes[2]. The studies on production technology of FCP have

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continued since the past, but there are still many difficulties. Because the molds cannot be reused in manufacturing FCP[3]. Therefore, each FCP requires different molds and wastes resources for that reason. And, the molds that cannot be recycled generate enormous amounts of construction waste and consumes too much social cost for waste treatment. Also, labor force is wasted because the molds need to be produced and assembled each time. All of these issues contribute to an increase in the construction period and cost when constructing free-form buildings.

Free-form panels are classified into single-curved panels and double-curved panels as shown in Figure 1[4]. The existing technology could manufacture the single-curved panels simply by bending. However, double-curved panels are easily deformed, so it needs special equipment or molds for production. Therefore, the cost of panel production is high and greater cost is consumed for maintenance.

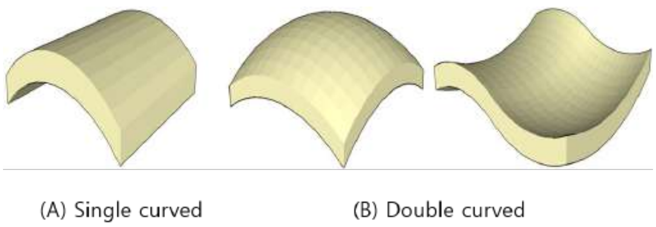

Figure 1. Types of Free-form Panels[4]

Therefore, it is necessary to develop a technology capable of producing the shape of the FCP completely. Therefore, this study develops FCP production equipment as shown in Figure 2 to compensate for the problems of existing FCP production technology. This equipment consists of side mould control equipment(A) that implements the side formwork of the FCP and two-sided multi-point press equipment(B) that implements the top and bottom formwork of the FCP. This study focuses on the development of two-sided multi-point press equipment(B) and proposes a method to improve the accuracy of this equipment to produce FCP of the perfect design shape.

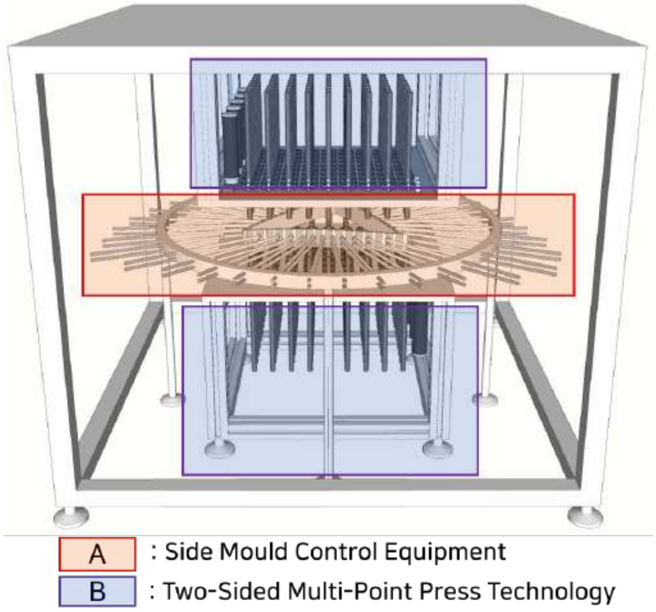

Figure 2. FCP Production Equipment

2. Theoretical Review

2.1 Existing Study Review

Jongho Ock (2012) conducted a study on the application of data overlap comparison method to improve the quality of construction of exterior panels for free-form buildings. He studied the free-form housing buildings in Korea. He used the 3D laser scanning technology to overlap and compare the exterior panel design of free-form housing buildings(As-Planned) and the outcomes of construction(As-Built). By doing so, he identified the problems related to the type of panels(flat, single-curved, and double-curved) and substantially analyzed the causes of problems by producing curved mockups of panels. However, the limitation of the study was that it considered the curved shape of panels only to improve the quality of exterior panels when you also need to consider the materials and construction of materials forming the waterproof and insulation layers beneath the panels and how to install the panels in addition to the curved shape of panels when determining the shape and curvature of free-form exterior panels. For this reason, he pointed out that additional studies would be needed[5].

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Junghwan Seo (2017) conducted a study on the mechanism to process EPS foam into molds to produce molds for free-form concrete. He suggested the EPS foam processor that consists of the cutting device that cuts the EPS foam and the Cartesian shift mechanism. The cutting device is installed on the Cartesian shift mechanism and uses the heating wires and bars to cut the EPS foam. This equipment uses the two switches on the cutting device to set the initial position of cutting device and moves the heating wires and bars to the coordinates entered to cut the EPS segments fixed onto the Π-shaped vise. He used the equipment to actually engineer and produce the molds in Figure 3. He expected to produce the molds that can save time and are economical to apply to various free-form construction sites[6].

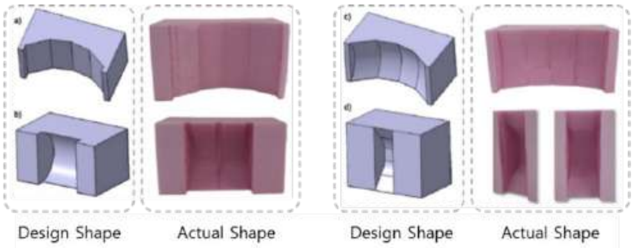

Figure 3. Engineered Models and produced Molds[6]

2.2 The Limitations of Current FCP Production Technology

The demand for free-form buildings is growing, but FCP production technology has a number of problems, such as increased construction costs and period, environmental waste generation. Therefore, there is a need to supplement the FCP production technology to solve these problems. In order to solve these problems, research on FCP production technology has been continued, but There is no research that can be put to practical use. The following are the reasons why the findings of the preceding studies have not been commercialized.

First, the CNC (Computer Numerical Control) machine produced in a preceding study to produce FCP(Free-form Concrete Panel) can only mold the bottom parts. The preceding study used the CNC equipment and paraffin to produce FCP as in Figure 4. Because the preceding study had to use the technology for molding the bottom to produce FCP, it used paraffin to produce a mold for both upper and lower curvature and poured concrete in between to complete FCP[7]. However, this method was too time-consuming. It was not very productive because it took too much time to melt paraffin and cure paraffin and it could complete just one piece of FCP with a pair of molds.

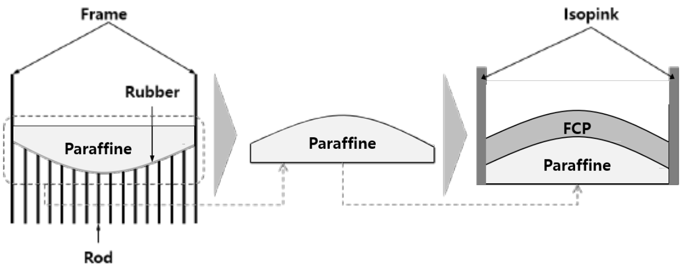

Figure 4. Method of producing FCP Suggested by the Preceding Study

Second, the exterior of free-form buildings is completed with several pieces of FCP, but the following problems occur when FCP is produced without considering the profile of form as with the typical concrete panels. Figure 5 shows the profile of FCP that is parallel on both sides. In case of typical buildings, the panels are assembled vertically or horizontally and the members do not overlap even when both sides are parallel. In case of free-form buildings, assembling FCP with parallel sides creates gaps or causes the members to overlap as shown in Figure 5[8]. Therefore, it is inevitable to fill in the gaps or trim the sides of FCP through additional processes in order to apply FCP with parallel sides, leading to longer construction periods and higher construction costs.

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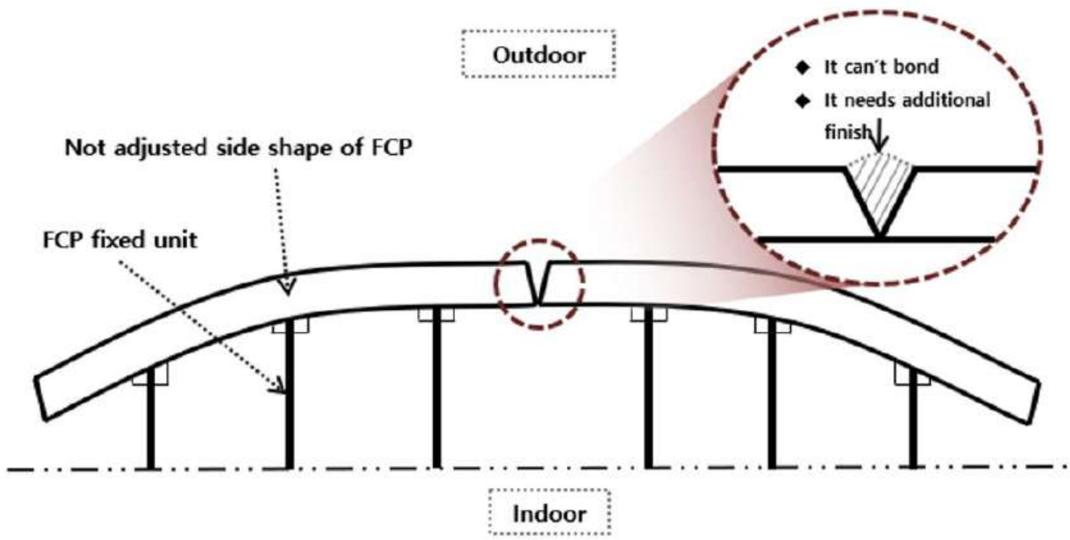

Figure 5. Problems of FCP produced Using the Existing Method

Lastly, the preceding study could only produced FCP that is rectangular. Like a soccer ball that uses pentagons and hexagons to create a sphere, it is necessary to produce polygonal FCP to create the perfect curvature of buildings. Considering that all polygons can be built with triangles, it is absolutely necessary to develop technology to produce triangular FCP. The major case of a free-form building comprised of free-form panels is the National Museum of Qatar. Figure 6 is the enlarged view of the roof of the National Museum of Qatar and it shows that the roof of the National Museum of Qatar is built with polygonal free-form panels that are not squares or rectangles[9].

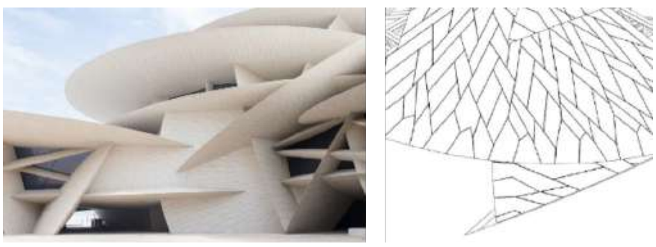

Figure 6. The Roof of the National Museum of Qatar

As can be seen in Figure 6, to realize the curvature of an free-form building, it is necessary to develop a technology capable of producing multiple angle FCPs. Therefore, this study develops the technology to produce FCP, and the development of this technology will contribute to the free-form construction.

3. Development of FCP production equipment technology

3.1 Development of Two-sided Multi-point Press equipment

The equipment under development in this study is the FCP manufacturing equipment as shown in Fig. 2. It consists of two-sided multi-point press equipment and side shape control equipment. Figure 7 shows the two-sided multi-point press equipment under development. The two-sided multi-point press equipment consists of a lower multi-point press and an upper multi-point press. This equipment is to implement the upper and lower formwork of FCP. The upper and lower formwork of FCP is implemented in the shape realization part as shown in Figure 8.

At this time, the form of the upper and lower formwork is realized through the rubber of silicon material combined with the rod of the upper and lower as shown in Figure 8. Rod can be controlled by inputting upper and lower shape data of FCP, and each rod moves by input data. Through this, the rod of the upper and lower part of FCP is combined with silicone rubber to finally realize the upper and lower formwork of FCP. After the formwork is realized through the side shape control equipment, concrete can be poured to produce various types of FCP.

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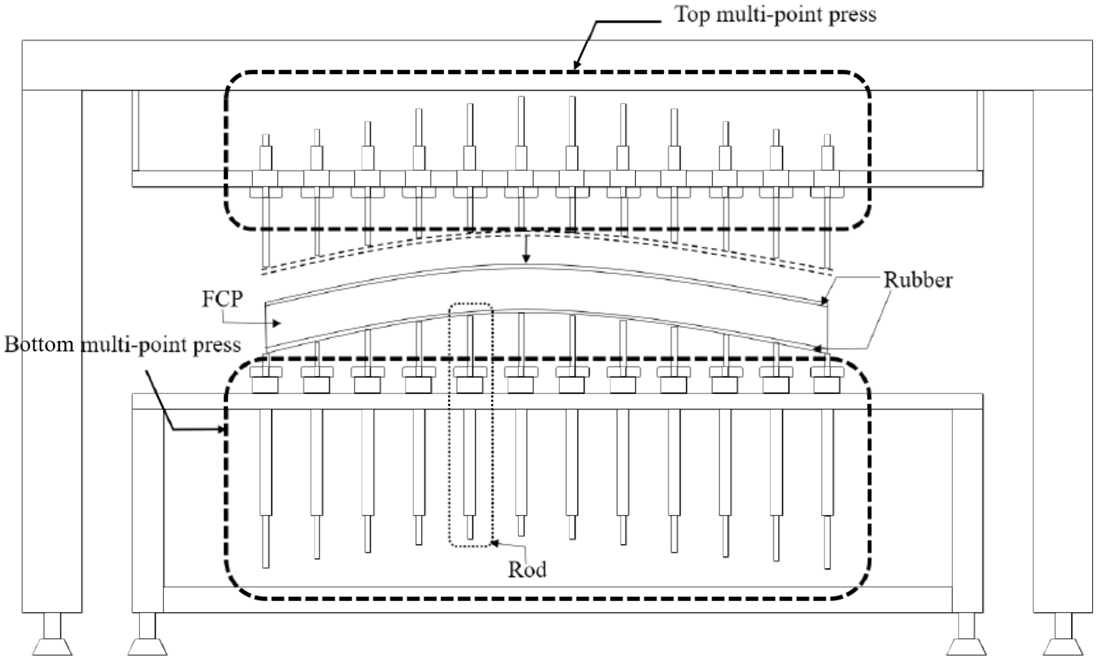

Figure 7. Two-sided multi-point press technology(2D)[10]

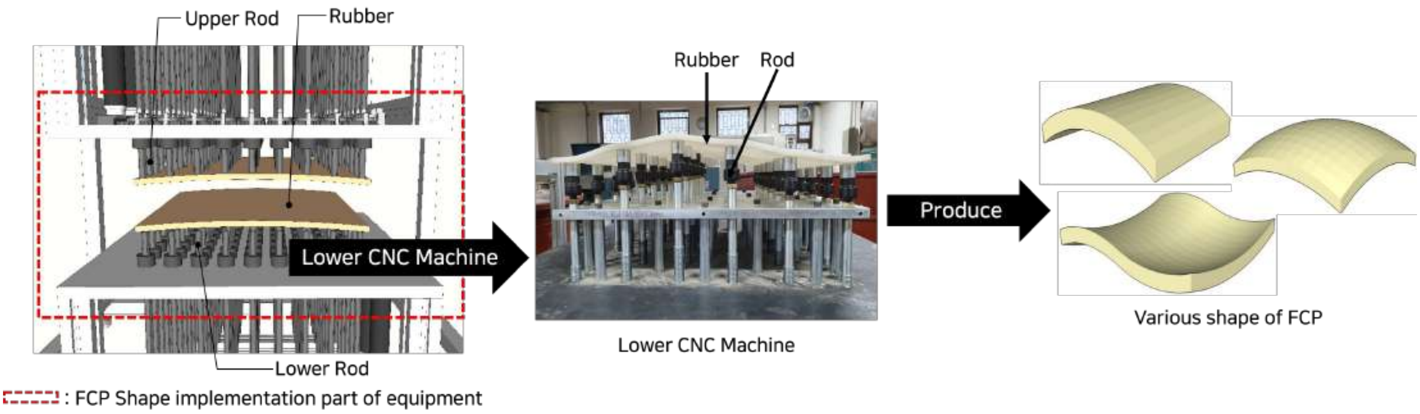

Figure 8. Two-sided multi-point press technology(3D)[11]

This study developed the prototype of the two-sided multi-point press equipment as shown in Figure 7 and faced two problems in this process. First, it is the matter of joints between the rubber and each rod. The joints of rubber and rods on the preceding study's CNC machine are fixed with epoxy resin and screws without any other tools. Also, the fixed rubber is as elastic as silicon and subject to the issue shown in Figure 9 when the curvature of FCP is expressed using each rod. The curvature of FCP is expressed by the movement of rod as with Rod2 and the rubber fixed between the two rods.

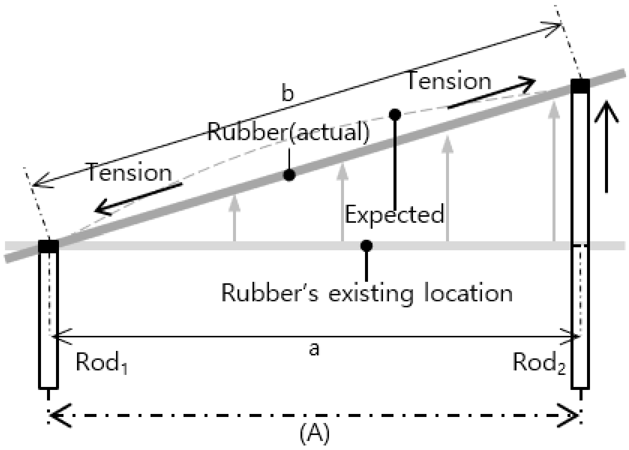

Figure 9. Problems with the Curvature of FCP

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The distance between the two rods increases from a to b, so tension applies to the fixed rubber. Section (A) between Rod1 and Rod2 is straight, not curved. This phenomenon occurs continuously between each rod, so the produced FCP expresses curves with a series of straight lines, not with an engineered curve. In order to resolve this, numerous rods can be used to shorten a. However, this is realistically impossible because of the technical limitations.

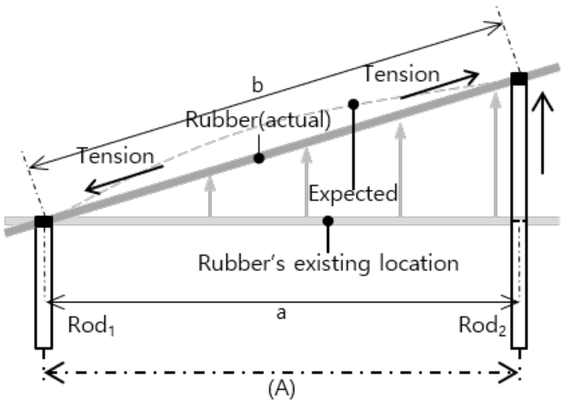

Figure 9. Problems with the Curvature of FCP

Because of the problems, this study installed a bearing at the end of the rod so the rod can rotate as shown in Figure 10 to produce FCP that are closer to curves. The following should be considered when applying the bearing to the rod: first. When the equipment is set at (2), which is a random curvature, from (1) with no curvature as shown in Figure 10, the length of movement of rod up and down should be considered. When the bearing is applied to the rod, the top of rod moves according to the gradient and curvature of rubber. The previous equipment adjusted the length of rod by B to express the curvature. However, the new equipment of the current study expressed the curvature of rubber with the movement of rod from top to bottom and the rotation of bearing, so the overall length of rod was C+D. Also, previous equipment adjusted the entire length of rod, whereas the new equipment fixes the C value and adjusts the D value only when the length of rod is adjusted. Therefore, it is necessary to consider these features when developing the equipment to produce more perfectly shaped FCP. Follow-up studies shall resolve these issues to develop equipment that can adjust the length of rod automatically when the shape of FCP is entered on a computer program.

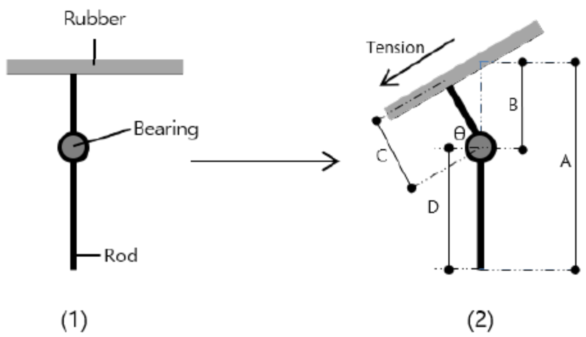

Figure 10. Basic Design of Rod Using Bearing

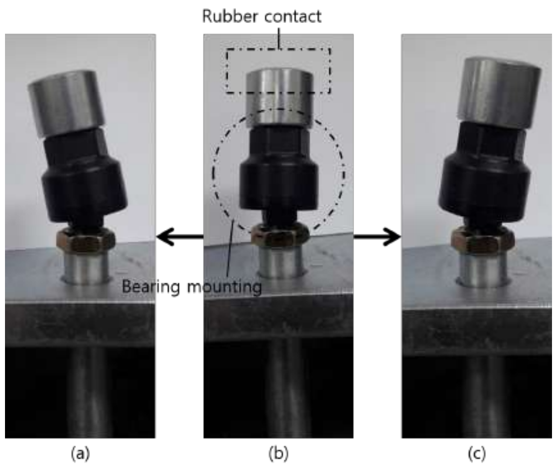

Figure 11. The Rod with Bearing

Figure 11 shows an image of a rod with bearing. The rod of the current study has the bearing on top as in (b) to rotate left and right as with (a) and (b). Also, the top of the rod can be connected to the rubber with screws. As pointed out in Figure 9, the straightness of rubber with tension can be prevented by moving the rod based on the predicted adjustment of rubber. Second, the thickness of FCP cannot be maintained consistently when top multi-point press and bottom multi-point press expresses the curvature of FCP. Figure 12 shows this in a drawing: (A) shows the production of FCP with two-sided multi-point press and (B) shows an enlarged view of FCP that is produced by (A).

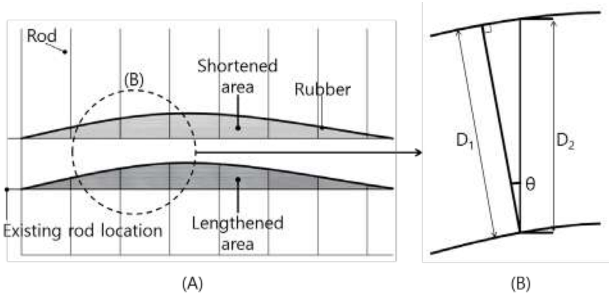

Figure 12. Actual Thickness of FCP and Difference between Rods

When producing FCP using top multi-point press and bottom multi-point press, as shown in Figure 12, the Rod of the upper and lower multi-point press in one section according to the curvature of the FCP moves in the same direction. In other words, when the length of the rod on top multi-point press shortens as the 'shortened area' according to the curvature of FCP, the rod on bottom multi-point press is extended as the 'lengthened area.' The thickness of FCP produced in this way is measured at a point that is perpendicular from a curve as in D1. For quality FCP, D1 is consistent throughout all sections. When producing FCP, the distance between the rod of top multi-point press and the rod of bottom multi-point press is D2, which is the vertical distance between top multi-point press and bottom multi-point press and the difference between D1 and D2 increases as the angle (θ) between D1 and D2 expands.

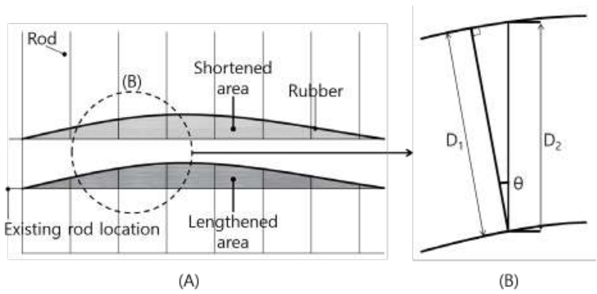

Figure 12. Actual Thickness of FCP and Difference between Rods

Figure 13 shows the difference between the vertical distance between rods of FCP and the thickness of each FCP point. In this study, we designed an FCP with a thickness of 50mm and a width of 600mm, and set the measurement points by 5 mm from point 1 to point 12. After that, the vertical distance a between the rods was measured to calculate a length difference from a '(50 mm) of FCP thickness.

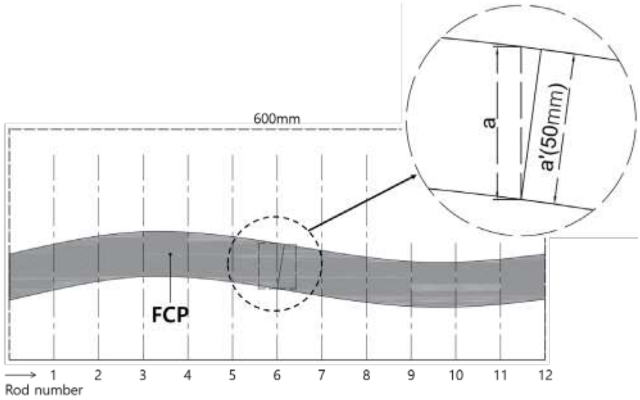

Figure 13. Vertical distance measuring model between top and bottom rods

Table 1 summarizes the measurement results in Figure 13. As can be seen from Table 1, the design shape FCP has a different distance (a) between the thickness value (a') and the upper and lower rods.

Table 1: Results of Analysis of Difference between the Thickness of FCP and the Vertical Length of Rod

Rod No.	Vertical length between rods (a)	Difference with thickness of FCP (a'-a)	Ratio of Difference with thickness (%)
1	51.13mm	1.13mm	2.26
2	50.57mm	0.57mm	1.14
3	50.04mm	0.04mm	0.08
4	50.10mm	0.10mm	0.20
5	50.42mm	0.42mm	0.84
6	50.65mm	0.65mm	1.30
7	50.63mm	0.63mm	1.26
8	50.38mm	0.38mm	0.76
9	50.09mm	0.09mm	0.18
10	50.02mm	0.02mm	0.04
11	50.23mm	0.23mm	0.46
12	50.35mm	0.35mm	0.70
Avg.	50.38mm	0.38mm	0.77

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3.1 Development of FCP thickness keeping technology

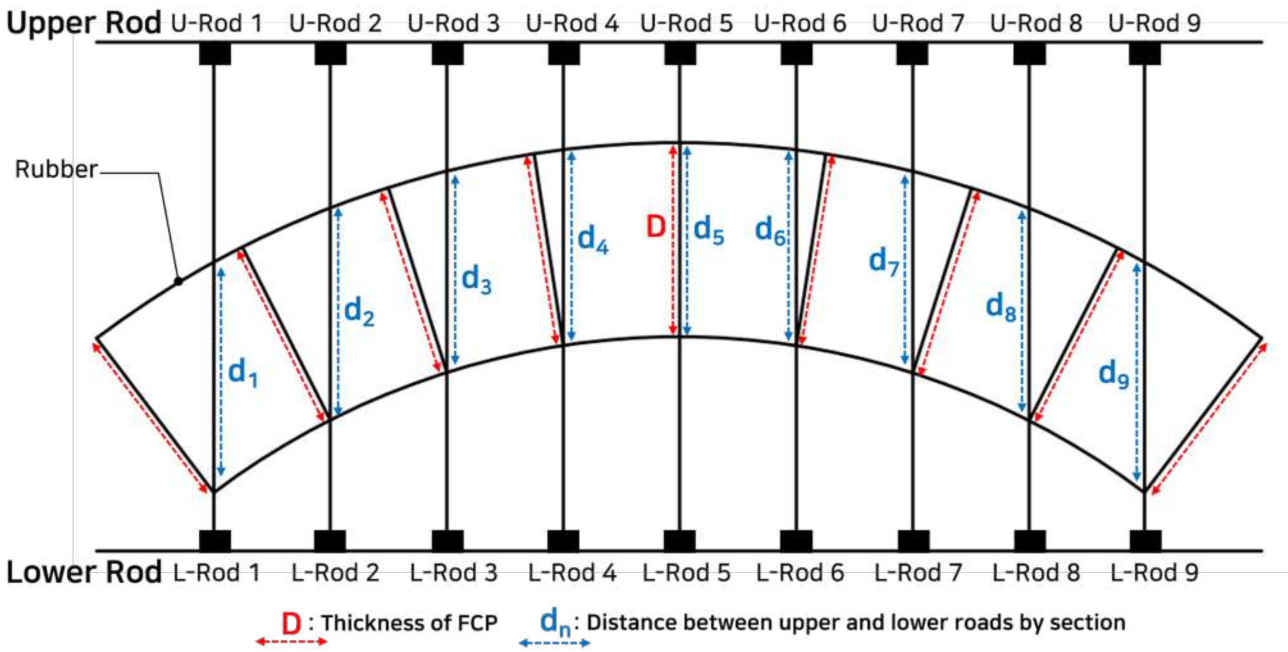

Figure 14. FCP thickness(D) and distance between upper and lower rods(dn)

As shown in Figure 14, the thickness of the FCP should always have a constant thickness (D) value for each section. And the upper and lower rods for each section should use the appropriate dn value which is the distance between the upper and lower rods, for the FCP to have a constant thickness (D) value for each section. However, since FCP is manufactured by extracting the exterior design of an free-form building and separating it into different types of FCPs, it has a wide variety of shapes. So it takes a lot of time to extract an appropriate dn value from the 3D BIM drawing for the FCP to have a constant thickness (D) value. In addition, the FCP is produced in a lying down state, and the lying angle varies from panel to panel, and the dn value changes every time. Therefore, when the lower formwork of the FCP is implemented through the lower rod driving, it is difficult to know the moving distance of the upper rod to maintain a constant thickness (D) value and cannot realize the form of the upper formwork [12]. For this reason, there is a problem that a complete FCP of design shape cannot be manufactured. To solve this problem, this study proposes the following data collection research.

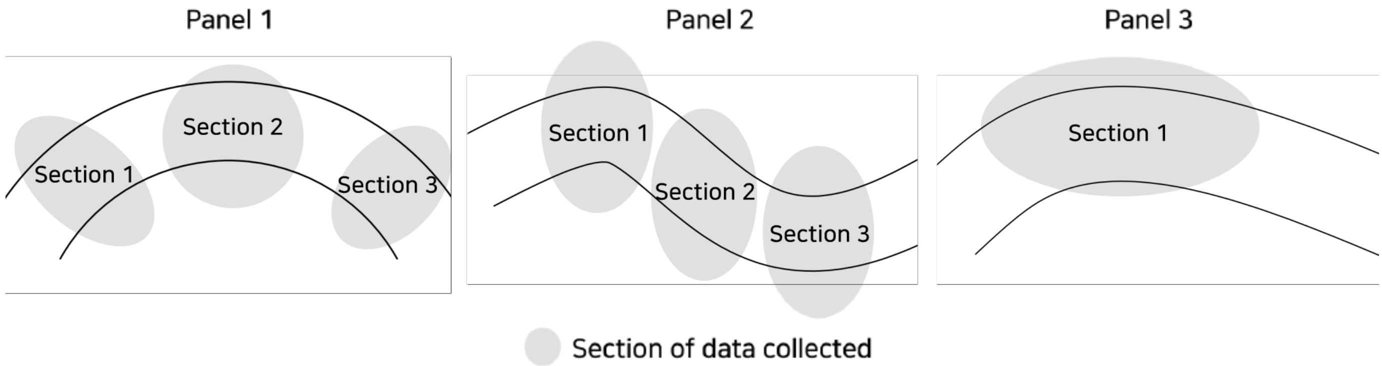

Figure 15. Various shapes of FCP

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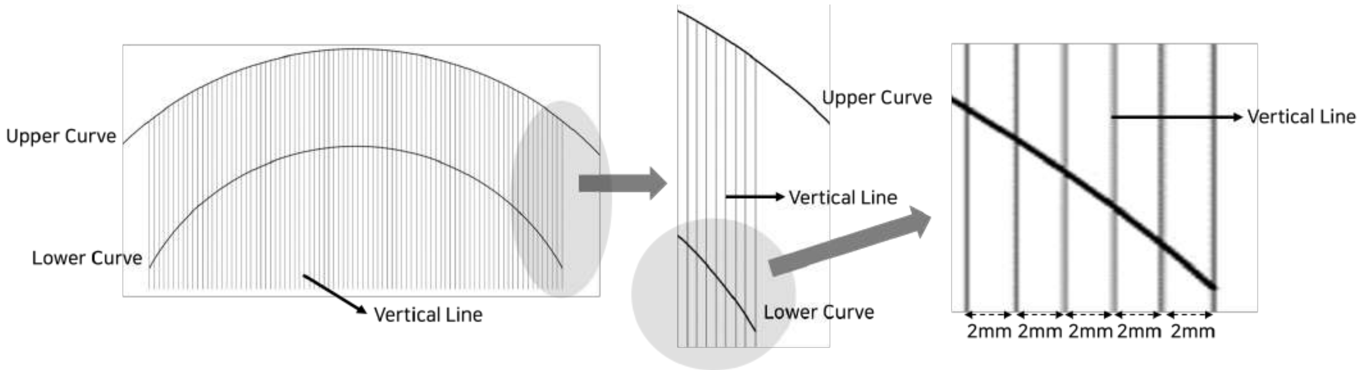

Figure 16. Panel segmentation using vertical lines

The method proposed in this study is as follows. First, using the CAD program, FCPs of various designs are drawn as shown in Fig. 15, and data is collected. At this time, the data section to be collected is as shown in Figure 15. These sections include the section where the curvature of the FCP rises and falls and the section where the angle of curvature becomes '0'. In this paper, we propose a study to collect curvature data for these sections. At this time, in order to analyze the curvature of the panel in detail, data are collected by drawing vertical lines at 2mm intervals along the lower curvature of the panel as shown in Figure 16.

Points A, B, and C are points where the vertical line and the lower curvature meet, and points where the vertical line and the upper curvature meet are the A ', B', and C 'points. At this time, the distance between A point and A 'point is dn(mm) and the distance between B point and B' point is dn+1(mm). In the same way, the distance between point C and point C 'is dn+2(mm). The distance between point B 'and K is a(mm), and the angle formed by the horizontal line drawn at line A'C' and point A 'is called θ. Data is collected a(mm), d(mm), and θ values for each section of the FCP, and the change of the d value for each section is analyzed according to the change of a and θ values. By using the method proposed in this study, we can confirm the dn values corresponding to the two values as shown in Table 2. Using this data, we can manufacture FCP while maintaining accurate thickness without trial and error.

In the case of manufacturing FCP through the above studies, it will be a basic study in implementing 'FCP automated production method' that can automatically infer FCP curvature based on the analyzed data. The method of automatically inferring the curvature of the FCP is shown in Figure 18. It implements one side of the FCP first and automatically infers the other through the analyzed data. In this study, we conducted a study on the development of FCP thickness keeping technology for the production of FCP of design shape. Data collection, as shown in Figure 17, is an essential step in the fabrication of the design features of FCP, which can be used as basic research data for FCP automated production as shown in Figure 18.

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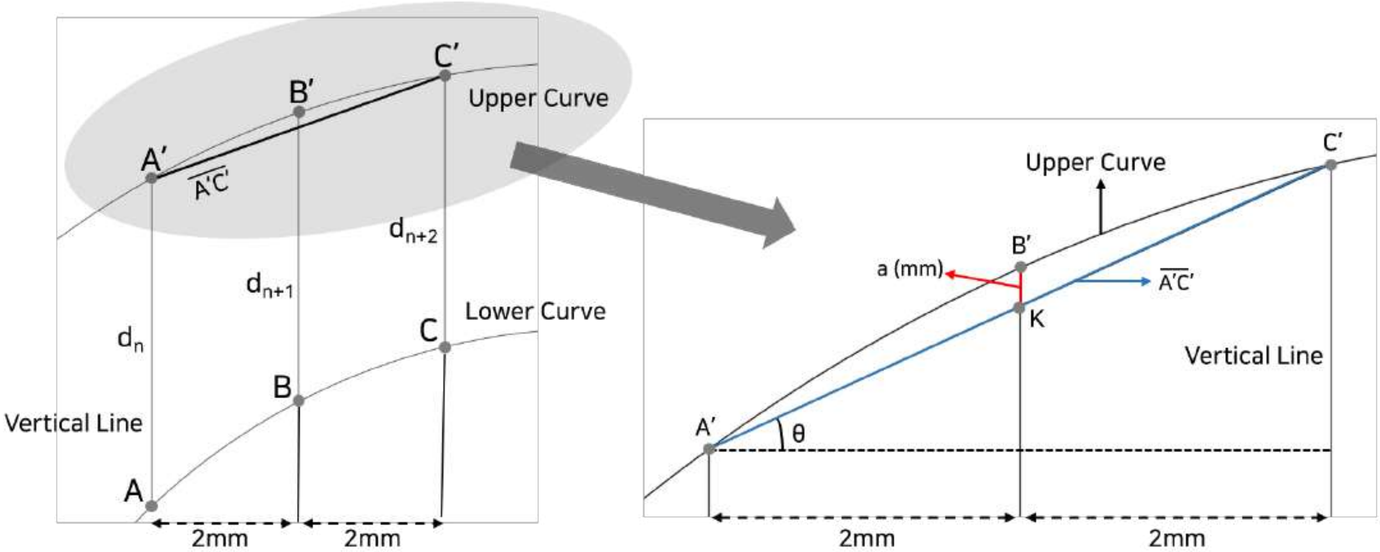

Figure 17. Measuring method of FCP curvature data

Table 2: Example of curvature data collection for FCP

Section No.	Section 1		
	a(mm)	θ	d_n(mm)
1	0.045	60	151.131
2	0.043	59	149.180
3	0.041	58	147.336
4	0.039	58	145.588
5	0.037	57	143.929
6	0.035	57	142.349
7	0.033	56	140.846
8	0.032	55	139.410
9	0.030	55	138.037
10	0.029	54	136.724

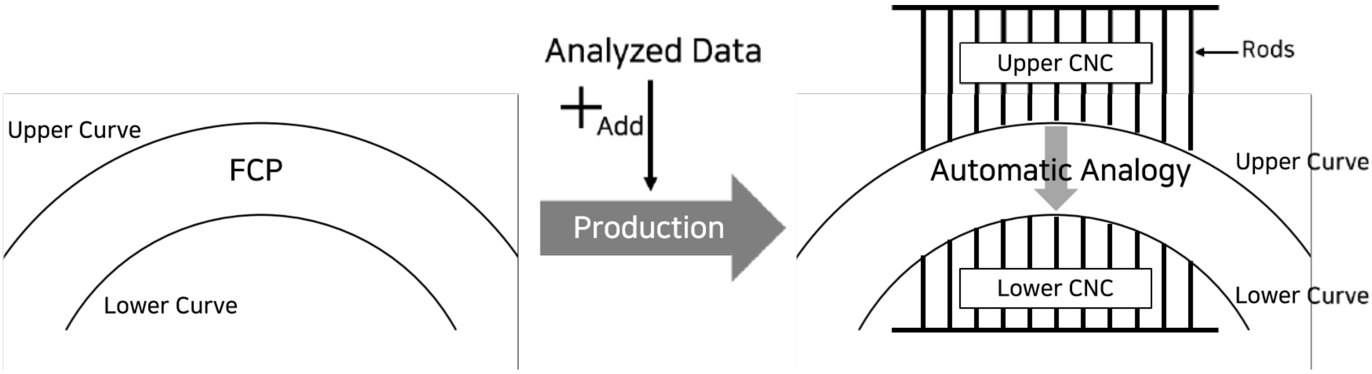

Figure 17. Measuring method of FCP curvature data

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4. Conclusion

In this study, basic research was conducted to develop equipment such as Figure 2 to solve problems with existing FCP production technologies. The equipment being developed consists of two-sided multi-point press equipment and side mould control equipment, and the research focused on the development of two-sided multi-point press equipment. two-sided multi-point press equipment is an equipment that implements FCP's top-and-bottom formwork and requires very key technology, so it is an object that needs to be studied intensively. Therefore, this study conducted a study on the mechanical part of the manufacture of two-sided multi-point press equipment and the solution for it. In addition, using this equipment, FCP studies have been conducted on the development of technical capabilities to ensure that FCP thicknesses are consistent because FCP build should be implemented exactly as the design features look. As a result of this study, problems with mechanical parts of two-sided multipoint press equipment have been solved through research, but studies to ensure the thickness of FCP are still insufficient. The technology that keeps FCP thickness constant is a very complex and difficult technology that requires a large amount of accumulated data. Therefore, this study proposed a new research plan to solve this problem, and we intend to solve it through further research.

5. Acknowledgment

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