

## A Study on the Measurement of Flexural Strength of Free-form Concrete Panel

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### Abstract

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With advancements in digital technology and construction techniques in modern times, buildings of diverse geometries are now being constructed. Many of these structures feature curved surfaces and are of large scale, and they are referred to as free-form architecture. Among the exterior panels of such free-form buildings, those made of concrete are termed Free-form Concrete Panels (FCPs). Since these panels are exposed to external environments, they are subjected to various external forces, and thus must exhibit resistance according to their specific geometries. Accordingly, this study aims to measure the bending behavior of FCPs among the various external forces acting upon them. A testing method for flexural strength test measurement will be proposed, and, if necessary, testing equipment will be developed to conduct the experiments. Through this research, differences in strength arising from variations in curved geometries can be identified, and it will also be possible to determine which shapes are most vulnerable to bending loads.

**Keywords:** *Free-Form Concrete Panel, External Force, Bending Strength, Flexural Strength Test.*

### Introduction

Since modern times, standardized buildings constructed with straight lines and flat, rectangular components have become the norm. This trend began with the start of industrialization, when populations began to concentrate in metropolitan areas and city centers, leading to the construction of tall, flat buildings to accommodate large numbers of people[1]. However, by incorporating curves and curved surfaces, it is possible to move beyond the standardized rectangular form and realize free and flexible shapes.

This approach allows for the preservation and expression of distinctive architectural designs. Moreover, buildings with diverse design forms can become iconic symbols representing each city or country. Such structures, by becoming brands in themselves, attract public attention and are expected to generate economic ripple effects as well as social, technological, and artistic success for the city or nation[2].

Some buildings with curved surfaces are called free-form building. There are some panels used as exterior components to realize the free curves and complex geometric shapes of free-form structures. Aluminum, steel, and glass etc. are used for free-form panels. Among these, some panels made of concrete are called free-form concrete panels (FCP)[3, 4].

Free-form concrete panels are used as exterior materials. Exterior materials are exposed to the elements, so they are susceptible to various stresses such as corrosion, cracking, and damaged by an impact[5]. Free-form concrete panels are thin. The stress state of members with thin structures, such as free-form concrete panels, is unstable. And bending and bending-shear stresses act in combination depending on the thickness of the panel. Therefore, bending has a greater effect depending on the member[6].

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This study aims to conduct flexural strength tests to evaluate the bending stress of free-form concrete panels used as exterior components. To this end, previous flexural strength tests were researched and analyzed. And the test equipment was necessary, so it was manufactured. Using this equipment, flexural strength tests will be performed on panels with various curvatures, and the differences in strength according to the panel shapes will be analyzed.

### Analysis of Previous Studies

#### Flexural strength test method for Korea industry standards

The test method for measuring flexural strength is specified in KS F 2408 Concrete Flexural Strength Test Method. KS F 2408 specifies that the test shall be conducted using the four-point loading method. The four-point loading method is a method of measuring flexural strength by supporting both ends of the specimen at the bottom and applying load to two points at the center of the top. The specimen is manufactured in accordance with the specimen manufacturing method for flexural strength specified in KS F 2403. This uses a beam-shaped specimen with dimensions of 40mm x 40mm x 160mm. The equipment used for the test is manufactured in accordance with the compression testing machine specified in KS B 5533. The measured load values are then calculated using the following formula[7, 8, 9].

$$f_b = pl/bh^2 \quad (2.1)$$

$f_b$  : Flexural Strength (MPa)

$P$  : Maximum load indicated by the tester (N)

$l$  : interdigital space (mm)

$b$  : width of the fracture surface (mm)

$h$  : Height of fracture surface (mm)

KS F 2408 specifies the center point loading method, but explains that it can yield larger values than the loads measured using the four-point loading method. The formula for calculating the load measured using the center point loading method is as follows.

$$f_b = 3Pl/3bh^2 \quad (2.1)$$

$f_b$  : Flexural Strength (MPa)

$P$  : Maximum load indicated by the tester (N)

$l$  : interdigital space (mm)

$b$  : width of the fracture surface (mm)

$h$  : Height of fracture surface (mm)

#### Strength measurement method for curved shape members

Kim (2008) evaluated the performance of lattice girders under bending loads using two test methods: the center point loading method and the four-point loading method. Lattice girders support the walls inside arched tunnels, distribute loads, and reinforce the structural rigidity and foundation. The study found that when testing members with curved shapes, the four-point loading method produced uniform stress, allowing for more accurate load values compared to the central point loading method[10].

Jeong (2016) performed bending strength tests to evaluate the performance of grid support members and used the four-point loading method for the bending strength tests[11].

The existing KS F 2408 specifies that the bending strength should be measured using the four-point loading method on a beam-shaped specimen. However, for components with curved surfaces like lattice girders, the load should be measured in their original state. When performing tests using the four-point loading method for load measurement, more uniform stress is generated, enabling accurate load measurement. Therefore, this study also aims to perform tests according to the four-point loading method.

### Flexural Strength Test for Free-form Concrete Panel

#### Test process

In this study, tests are conducted using a four-point loading method to measure the strength of irregular panels. The equipment used is a Universal Test Machine (UTM). Since the purpose of this study is to compare the strength differences between irregular concrete panels of different shapes, the specifications and shapes of the irregular concrete panels are kept constant, and the maximum vertical displacement is varied. The panel specifications were set to 400 mm × 400 mm × 35 mm, and the shape was a one-directional curved surface. The maximum vertical displacements were set to 0 mm, 10 mm, 20 mm, and 30 mm, respectively.

To measure the bending strength, a loading point equipment was fabricated to capable of distributing the load at two points in the center. The equipment was made by steel plate with a thickness of 15T. Two steel plates were stacked, and two hemispheres were placed at the bottom to form the loading points.

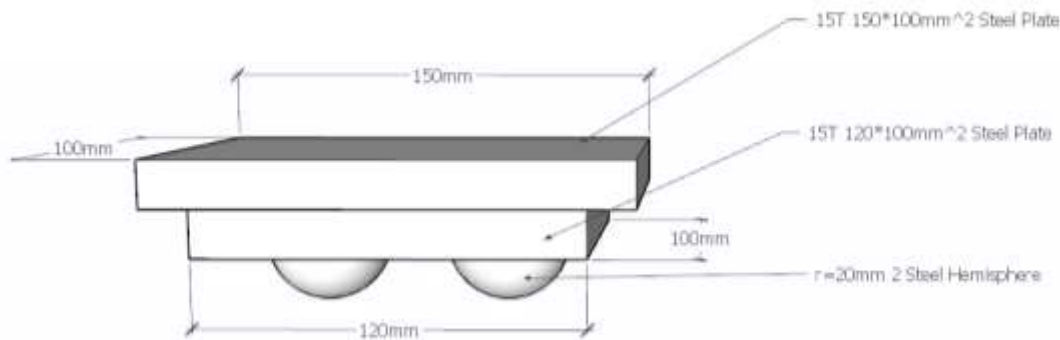


Fig. 1 Concept Photo of Bending Strength Measuring Equipment

The concrete mixing ratio was made using the mortar mix used in previous studies. The water-to-cement ratio was set at 40%, and polyvinyl alcohol (PVA) fibers were used because mortar is susceptible to cracking. In addition, a superplasticizer was added to facilitate concrete flow into the corners of the formwork during placement, as compaction was difficult. The ratios of fibers and superplasticizer were 1.5% and 0.3%, respectively. The mixing ratio are shown in the following table.

Table 1. Mixing ratio of Free-form Concrete Panel

W/C (%)	C (g)	S (g)	W (g)	PVA (g)	Superplasticizer (g)
40	7,333.334	3,667.667	2,933.334	110	22

In addition, the concrete was cured in a constant temperature and humidity chamber at a temperature of 20°C and a humidity of 60% for seven days.

A Universal Test Machine (UTM) was used to measure the flexural strength of the cured irregular concrete panels. The UTM can measure the compressive and flexural strength of specimens, and settings for measuring the strength of architectural boards were used. The load was applied to the center of the panel to measure it bending strength. The experimental process is shown in the following photo.



resistance to bending. Therefore, bending strength evaluation must be conducted. To this end, bending strength tests were performed to analyze the load values measured for each curved surface shape.

The experiment was conducted using a UTM, and the test method was performed using a four-point loading method. The mixing ratio of the free-form concrete panels was fixed, and the test was conducted by varying the shape. The panel shapes were curved panels with maximum vertical displacements of 0 mm, 10 mm, 20 mm, and 30 mm at the center.

The bending strength was measured to be the highest for the flat-shaped panel with a maximum vertical displacement of 0 mm. As the maximum vertical displacement increased, the bending strength value decreased. This indicates that strength differences occur depending on curvature, and the larger the curvature, the lower the measured bending strength.

This study focused on measuring one-way panels. But free-form panels come in various shapes, so strength measurements should also be performed on panels with diverse forms. Additionally, since cracks occurred concentrated at a single location during bending strength measurements, it is inferred that bending stress was concentrated at that point. The equipment should be improved to ensure uniform bending stress distribution.

Therefore, this study confirms that panels with curved surfaces must be manufactured with appropriate mix ratios to ensure resistance to bending. Since strength differences occur depending on the panel shape, quality measurements are required for free-form panels based on their manufactured shapes. This study provides direction for measuring bending strength and confirms the need to improve the accuracy of bending strength measurements in the future.

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