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The Relationship between the Internal Structure of a Bridge and its Strength

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Abstract

Our goal is to make stronger bridges by using prisms in their construction. We used triangular prisms, cuboids, and hexagonal prisms because they are said to produce strong structures in architecture. We think the bridge using a hexagonal prism may be the strongest because the forces scatter as in many angles as possible. We performed experiments by making models and using computer simulation.

１. Introduction

Most bridges made of concrete have their structures entirely filled with concrete. Our opinion is that bridges can be built by making use of prisms in their inner structure. By using them, the bridges can keep the same strength as the present ones have, and while building them we can reduce materials used and shorten the construction period. For our research, we used triangular prisms, cuboids and hexagonal prisms.

２. Experiment 1

<The process of the experiments>

First, we made five bridges by using a special kind of sand which gets water.
Second, we set each model between the two stands. We placed a bag on the center of each bridge, then we put plastic bottles, one by one, into the bag to figure out how much weight each model could sustain before it collapsed. We used 400g bottles and 11 500g bottles.

<The result of experiments>

It was impossible to compare fragility because the models were very weak and broke down too quickly during the experiment.

３. Experiment 2

<The process of the experiments>

In the second experiment, we decided to use a 3D printer to make models which were more durable. We designed the bridge with Fusion 360, a 3DCAD software, and the 3D printer in our school printed the models. The materials of those models is ABS resin. We made three kinds of models: triangular prisms, cuboid, and hexagonal prisms. Then we performed the experiments like those in Experiment 1.

However, the ABS resin was too durable to be broken. So instead, we tried to measure how much the models bent when the weight was placed on them. We performed the experiments with each of the 3 models and analyzed the data. The data showed a direct proportion between the weight we placed on the models and the bend of the models. We calculated the proportionality constant by using Excel. The proportionality constant means how much the models bent when we placed a particular weight on them. To clearly observe the bend, we used a laser beam. We made use of its reflection so that we could make even a very slight bend visible. The models were different in weight because their shapes were different. Therefore, we had to create a method to compare their bend with one another. So, we decided to use this formula.

FoB (Fragility of the Bridge)

$$\frac{Bend\ of\ the\ bridge\ per\ 1g\ weight}{Weight\ of\ the\ bridge\ itself}$$

This is our original formula. The smaller this value is, the stronger the structure is.

<The result of experiments>

Form	Fragility of bridges [mm/g^2]
triangular prisms	3.2×10^{-5}
cuboids	2.2×10^{-5}
hexagonal prisms	2.9×10^{-5}

The value of the triangle prism bridge was the largest, and the value of the bridge with cuboids were the smallest. From this result, we found that the structures using cuboids are the strongest, and the structure using the triangular prisms are the weakest.

<The consideration of experiment>

The model bridges using cuboids were the strongest and the one using the triangular prisms were the weakest, so we believe that the more perpendicular structures the girder bridge has, the more resistant it is to the force from the top. However, since the force was applied only to the central part of the bridge, it is not necessarily a completely accurate result.

4. Experiment 3

<The process of experiments>

We used a computer simulation system in Fusino360, which we used for making 3D models, so that we can perform the experiments virtually and accumulate exact data. In Experiment 3, we made seven new models. This time, we put a piece of “board,” vertical to the girder into the model bridges, and we also made a model bridge which did not have any prism inside for comparison. We calculated the weight of the bridges, and then we weighed down the bridges with extra force (20,000N) on their upper surface. We defined the formula below as “the fragility of the bridge.”

<The result of experiments>

Form	FoB
No prism	2.94×10^{-3}
Triangular Prisms	6.57×10^{-3}
	6.23×10^{-3}

Form	FoB
Cuboids	13.0×10^{-3}
	8.99×10^{-3}
Hexagonal Prisms	8.38×10^{-3}
	7.02×10^{-3}

<The consideration of experiment>

In our experiment, the bridge with no prisms was stronger than any other bridge which has prisms inside. The triangular prism was stronger than the hexagonal one, which was stronger than that with cuboids. We have discovered that by adding one vertical board to the prism bridges, we can improve the strength of the bridges because the value of “the fragility of the bridge” was decreased when a board was added.

Form	Decreasing rate
Triangular prisms	5%
Cuboids	31%
Hexagonal prisms	16%

5. Conclusion

We have found that the bridge without any prism structures is the most durable bridge, and using a vertical board in the bridge makes it stronger. However, Experiment2 and Experiment 3 produced different results. This may have been caused by one of three reasons. First, we did Experiment 2 with the same 3D models again and again. Repeated use may have affected the models. Second, we could not make 3D models which were perfectly homogeneous. Third, in Experiment 2 and in Experiment 3 our methods of adding weight to the bridge were different. In Experiment 2, we added the weight at one point in the center of the model and in Experiment 3 we did it across the entire surface of the model.

6. References

・「図解・橋の科学―なぜその形なのか?どう架けるのか?」
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7. Key words

bridge structure triangular prisms cuboids hexagonal prisms