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Monkey Saddle Grid-shell: Construction Methods

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Abstract

The particularity of the grid-shells (shells with removed material to create a grid of members following various directions) is that they are not erected in their final shape. The structure is first assembled as a two dimension grid mat on the ground and then during the construction process the supports are pushed to form the desired shape.

Surfaces with more than one curvature are the most suitable choices of geometry for shell structures, since only tension or compression stresses are created in the thickness of the shell, [1]. Among these, monkey saddle surface (a triple curved minimal surface) is this paper's matter of interest.

Surfaces with two or three curvatures can be constructed with one of the grid-shell construction methods (upward or downward method), when each group of the parallel grid members follow one of the mean curvatures. In the monkey saddle grid shell, each of the three groups of grid members follow one of its triple curvatures, only once among the infinite directions possible. Not following the curvatures, the grid-lines cannot be straight elements anymore. So the grid members should be curved elements before bending or they should endure torsional stresses. Both solutions make the construction process complicated.

The aim of this study is to make the monkey saddle grid-shell constructible, thus four methods of construction are proposed and compared with each other, methodically and financially. The grid members are modeled in grasshopper and the possible errors, each method might have, are extracted through the software's calculations.

Keywords: monkey saddle, grasshopper, grid-shell, minimal surface, constructability.

Introduction

The structures that will now be described are inspired from shell structure as they have the same geometry and the same kind of structural behavior. Grid-shells are basically shells where material has been removed to create a grid pattern. Where in a plain shell an infinite number of load paths were available, in a grid-shell the internal forces are carried by members and therefore have to follow a restricted number of paths, [1].

The principle of the grid-shell's erection process is to exert forces on two dimension grid mat so to deform it into the final shape. The same way as when one pushes on the edges of a sheet of paper to give it a tunnel or a hill like shape, the edges of the grid are basically pushed towards each other in order to match the predicted curve of the building. Then once the boundary conditions are set the structure is pulled and pushed at certain points to give its mountainous form to the structure, [1].

Just as shell structures, grid shells can be constructed according to a mathematical surface. To decrease the material required, a Minimal Surface is used. Intuitively, a Minimal Surface is a surface that has minimal area, locally. Physical models of area-minimizing minimal surfaces can be made by dipping a wire frame into a soap solution, forming a soap film, which is a minimal surface whose boundary is the wire frame. The monkey saddle surface is a Minimal Surface whose mathematical information is explained in the next paragraph.

In mathematics, the monkey saddle is the surface defined by the equation below:

$$z = x^3 - 3xy^2 \qquad (1)$$

The monkey saddle surface has three mean curvatures and a strict saddle point at the origin. So to have a grid-shell base on a monkey saddle form it should have a triangular grid with three groups of parallel members.

In the figures 2 to 5 we can see a development from a single curvature surface to a four curvature one (the dog saddle: a surface with a saddle point having four downward sloping regions ,for the dog's legs, separated by four upward sloping regions). This process can be continued to make more complicated saddles with more slopping regions, all of which belong to the minimal surface category, "Figure 1". The hyperbolic paraboloid "Figure 3" is often called a horse saddle surface, because a person could sit on it comfortably. A monkey, however, would run into trouble because he would have nowhere to put his tail! The surface in "Figure 4" is called a monkey saddle, because it has a convenient dip in the back to accommodate the monkey's tail, [2] & [3].