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Parametric design and mechanical performance analysis of hyperbolic flat reticulated shells

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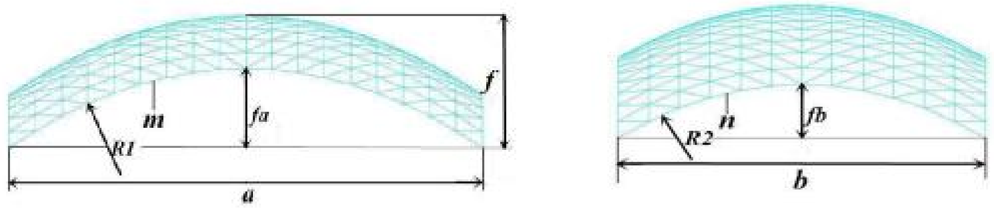
Abstract. A parametric design macro program of five kinds of hyperbolic flat lattice shells was developed by using APDL (Ansys Parametric Design Language) parametric design language.On this basis, hundreds kinds of working conditions of three kinds of hyperbolic flat lattice shells were selected for the change of long and short span of vector high , and did the structural force performance comparison analysis. In these three types of hyperbolic flat latticed shells, the three-dimensional lattice-type reticulated shell has the most reasonable mechanical properties,with long span of the ratio of vector high to span fa/a= 1/3 and short span of the ratio of vector high to span fb/b=1/6 are suitable. those provides a reference for practical engineering design.

Introduction

Four-point support double-curved flat reticulated shell structure is broad, beautiful appearance, and it occupies a certain position in large span buildings[1].The reticulated reticulated shells [2] can be divided into three types: monoclinic type, fuber type, three-way lattice type .This type of reticulated shell is mostly used for roofing. By analyzing the mechanical properties of such reticulated shells, it is possible to provide important materials for engineering examples.In this paper, the mechanical properties of five types of biconitic flat shells are discussed by using a long span a = 60m and a short span b = 40m model.

Macroscopic Geometric Parameters and Geometric Description of Hyperbolic Flat

The main parameters of the biconitic flat reticulated shell are: the length of the reticulated shells, the long side a, the short side b, the long side vector high fa, the short side vector height fb and the midplane high f, the long span direction grid m, the short span direction grid n (Figure 1).



(a) Structure front view（a=60, f_a=10, f=16.7, m=18） (b) Structural side view（b=40, f_b=6.7, n=12）

figure 1 The macroscopic geometric dimensions of the structure of hyperbolic flat reticulated shell

Parametric Design of Single Slanting Type Hyperbolic Flat

In the Cartesian coordinate system, given a, b, f, f_a, f_b, m, n, when $f = f_a + f_b$ [6], the hyperbolic flat shell surface equation is: $z = f - [f_a(\frac{2x}{a})^2 + f_b(\frac{2y}{b})^2]$

(1)Calculate node coordinates, define node number:

The node number is:$(i-1)\times(n+1)+j$,$(1\le i\le m+1$、$1\le j\le n+1)$;The node coordinates are:$x=(i-1)\times a/m$, $y=(j-1)\times b/n$, $z=f-[4f_a/a^2\times((x-m/2)\times a/m)^2+4f_b/b^2\times((y-n/2)\times b/n)^2]$,$(1\le i\le m+1$、$1\le j\le n+1)$.

(2)Bar connection: the structure is divided into six parts of the bar connection, respectively, long span direction, short span direction, four obliques。

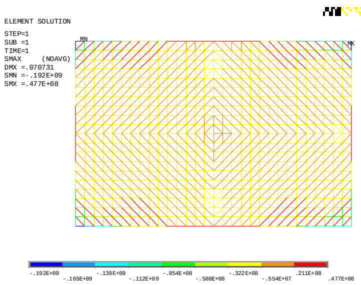
The connection number ,$(i-1)\times(n+1)+j$ and $i\times(n+1)+j$ （$1\le i\le m+1$、$1\le j\le n+1$）,the node is a long span bar； The connection number ,$(i-1)\times(n+1)+j$ and $(i-1)\times(n+1)+j+1$ （$1\le i\le m+1$、$1\le j\le n+1$）the node is a short span bar； The connection number ,$(i-1)\times(n+1)+j$ and $(i-1)\times(n+1)+j+n$ （$1\le i\le m+1$、$1\le j\le n+1$）,the node is the upper left corner of the oblique bar;The connection number ,$(i-1)\times(n+1)+j$ 和$(i-1)\times(n+1)+j+n+2$ （$1\le i\le m+1$、$1\le j\le n+1$）,the node is the lower left corner of the oblique bar； The connection number ,$(i-1)\times(n+1)+j$ and $i\times(n+1)+j+1$ （$1\le i\le m+1$、$1\le j\le n+1$）,the node is the right upper corner oblique bar； The connection number,$(i-1)\times(n+1)+j$ and $(i-1)\times(n+1)+j+n$ （$1\le i\le m+1$、$1\le j\le n+1$）,the node is the right lower corner oblique bar.

Apply loads and constraints

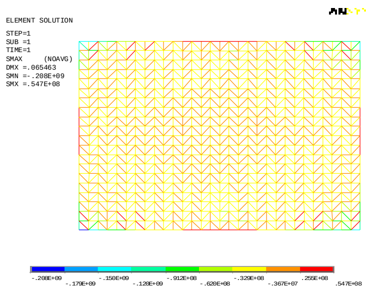
The beam-4 element (subjected to axial tension and compression, torsion and bending load) in the Ansys software was used as the structural member, and the ideal elastic-plastic material model was used, not considerring material hardening。The material density $\Phi 273 \times 6.5$, material density $\rho = 7850kg / m^3$, allowable strength $[s] = 215MPa$, elastic modulus $E = 2.06 \times 10^{11} N / m^2$, Poisson's ratio $\varepsilon = 0.3$.Considering the weight of the structural bar and the node, the equivalent load of the roof $2.35kN / m^2$,is applied to all nodes of the reticulated shell.All the rods in the reel are taken with the joints, and the four supporting points are hinged.

Analysis of Mechanical Performance of Five Kinds of Hyperbolic Flat Shell Structures

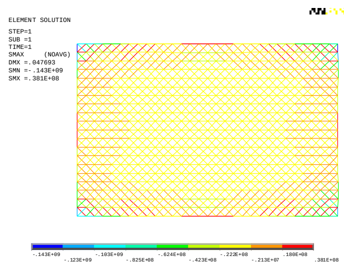
According to the technical structure of space grid structure 3.5.1 [7], the maximum deflection value of single-layer reticulated shell should not exceed 1/400 of the shortest span, and the allowable stress is the design value of steel 215Mpa.Figure 2 shows the stress cloud and the displacement cloud after the load, the analysis data in Table 1 of the structure of the five biconitic flat shells under the conditions of a = 60m, b = 40m, f_a = 10m, f_b = 6.7m, $f = f_a + f_b$ = 16.7m, m = 30, n =20.



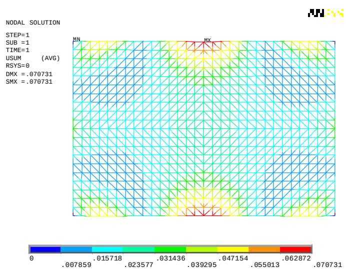
（a）Single diagonal bar stress cloud



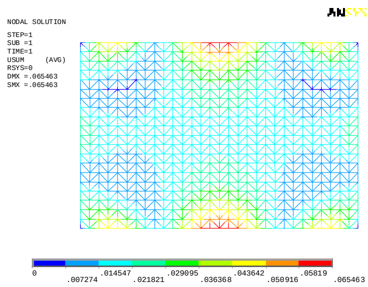
（b）Fubler stress cloud



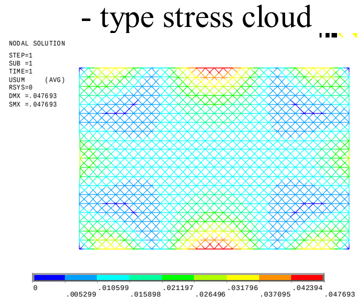
（c）Three - dimensional lattice - type stress cloud



（d）Single diagonal bar Displacement cloud



（e）Fubler Displacement cloud



（f）Three - dimensional lattice - shaped displacement cloud

Fig.2 Stress cloud and displacement cloud diagram of three kinds of single-layer hyperbolic flat reticulated shells（a=60m，b=40m，f_a=10m，f_b=6.7m，$f=f_a+f_b$=16.7m，m=30，n=20）

Table 1 Comparison of Maximum Displacement and Maximum Stress Impact of three Hyperbolic Flat Shell Types

structure type	Long span (m)	Short span (m)	Long span vector (m)	Short span vector (m)	Long span grid number	Short span grid number	The maximum displacement of the structure (m)	Structure Maximum stress (± Mpa)	
Single diagonal type							0.071	47	-192
Fubel type	60	40	15	10	18	12	0.065	55	-208
Three-way lattice type							0.048	38	-143

It can be seen from Fig. 2 and Table 1 that under the action of uniform load of 2.35 kN / m2, considering the structural weight (bar and node):

The maximum displacement of the five kinds of single-layer hyperbolic flat reticulated shells satisfies the structural stiffness requirements (the maximum displacement is less than 100mm). The maximum displacement is in the middle of the long span. The maximum displacement of the three- But are less than the allowable displacement of the structure. The minimum displacement of the structure is symmetrically distributed in the four blue regions of the displacement cloud.

The influence of the length and length of fa, fb on the mechanical properties of reticulated shells

The mechanical properties of three types of single - layer hyperbolic flat reticulated shells were investigated by taking fa / a = 1/3 ~ 1/6 and fb / b = 1/3 ~ 1/6, 60m, b = 40m, m = 18, n = 12, the analysis data in Table 2.

Table 2 Comparison of the relationship between the maximum displacement of the structure and the maximum stress

structure type	Long span vector span fa / a	Short span vector ratio fb / b	The maximum displacement of the structure (m)	maximum stress Structure permissible displace ment (m)	Structure Maximum stress (± Mpa)		Structure allowable stress (Mpa)
Single diagonal type	1/3	1/3	0.0659	0.1	29	-120	215
		1/4	0.0653		27	-115	
		1/5	0.0651		29	-112	
		1/6	0.0647		30	-110	
	1/4	1/3	0.0549		28	-125	
		1/4	0.0560		29	-125	
		1/5	0.0585		29	-124	
		1/6	0.0604		31	-123	
	1/5	1/3	0.0507		28	-126	
		1/4	0.0544		28	-129	
		1/5	0.0578		30	-131	
		1/6	0.0607		31	-132	
	1/6	1/3	0.0489		30	-126	
		1/4	0.0529		31	-132	
		1/5	0.0569		30	-135	
		1/6	0.0604		31	-138	
Fubel type	1/3	1/3	0.0643	0.1	28	-129	215
		1/4	0.0631		29	-124	
		1/5	0.0625		31	-120	
		1/6	0.0616		33	-117	
	1/4	1/3	0.0526		31	-135	
		1/4	0.0534		28	-134	
		1/5	0.0546		31	-133	
		1/6	0.0564		34	-132	
	1/5	1/3	0.0470		35	-135	
		1/4	0.0506		33	-139	
		1/5	0.0541		31	-140	
		1/6	0.0569		34	-141	
	1/6	1/3	0.0453		37	-135	
		1/4	0.0492		36	-141	
		1/5	0.0531		35	-144	
		1/6	0.0565		34	-147	
Three-way lattice type	1/3	1/3	0.0411	0.1	25	-100	215
		1/4	0.0401		26	-101	
		1/5	0.0394		26	-100	
		1/6	0.0384		27	-98	
	1/4	1/3	0.0349		24	-97	
		1/4	0.0355		26	-102	
		1/5	0.0370		26	-103	
		1/6	0.0380		26	-102	
	1/5	1/3	0.0318		25	-94	
		1/4	0.0348		24	-101	
		1/5	0.0372		26	-104	
		1/6	0.0391		26	-105	
	1/6	1/3	0.0307		26	-92	
		1/4	0.0339		26	-101	
		1/5	0.0368		24	-105	
		1/6	0.0391		25	-107	

We can see from Table 2 :

The maximum displacement or the maximum stress of the structure increases with the increase of t he short span vector, and as the long span vector is larger, the maximum displacement or the maximu m stress increases with the increase of the length of the span. The maximum displacement or the maxi mum stress of the structure increases and then decreases with the increase of the short span vector.W hen the short span vector is large, the maximum displacement or maximum stress increases with the i ncrease of the long span vector. With the decrease of the short span vector, the maximum displaceme nt or the maximum stress increases with the increase of the long span vector Reduced. The minimum value of the maximum displacement or maximum stress of the structure appears at the ratio of f_a / a = 1/6, f_b / b = 1/3 or f_a / a = 1/3, f_b / b = 1/3.

Conclusions

In this paper, the changing behavior of the single-layer hyperbolic flat shell structure under 130 working conditions is discussed, and the following conclusions are drawn:

In the three types of single-layer hyperbolic flat reticulated shell structure, the three-way grid type of the most reasonable performance, in the actual engineering design, can be preferred; The change of long and short span vectors has a certain influence on the maximum displacement and maximum stress of three types of single-layer hyperbolic flat shells; The mechanical properties of the three kinds of single-layer hyperbolic flat reticulated shells meet the structural strength stiffness requirements under the optimal vector span ratio and the optimal grid number.

Single-layer hyperbolic flat shell to meet the requirements of the performance requirements under the premise of the bar should be optimized to cross-sectional size, so as to achieve the purpose of the lowest consumption of steel.

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