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Analysis of stability and stiffness of spacer grid

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ABSTRACT: The stiffness、critical loads and buckling modes are very important and neccessary mechanical characteristics of spacer grid of fuel assembly both for dynamic analysis of fuel assembly and for safty analysis of spacer grid. Because of complexity, they are usually determined by experiment. The present paper successfully performed the stiffness and stability analysis of spacer grid by finite element method. The three dimensional model for calculating takes into account dimples, springs, fuel rods and guid thimbles. And the effects of each component on the stability and stiffness of the spacer grid are investigated. So these characteristics can be predetermined before manufacturing.

1 INTRODUCTION

Spacer grid is a crucial component in the design of fuel assembly and its stiffness and stability are not only the impotant item to the safety evaluation of fuel assembly but also important parameters in dynamic analysis of fuel assembly (vibration、earthquake and LOCA ete). Because of complex structure of spacer grid, it is difficult to calculate these mechanical characteristics, and experimental methods are usually applied. However, experiments can't be carried out before spacer grid is designed and constructed. On the other hand, different institutes have given different experimental results concerning these characteristics. A theoretical analysis method is presented in this paper. According to the method, mechanical characteristics of spacer grid like stiffness、buckling modes and critical loads can be calculated at any time in the process of design. Meanwhile, the effects of each component in spacer grid on global characteristics can be explored. The solution to this problem by experiments is obviously difficult both in cost and technique. The combination of theoretical analysis and experiment will deepen the research of fuel assembly.

2 ANALYTICAL METHOD AND COMPUTATIONAL MODEL

2. 1 *Analytical methocl*

So far, stability analysis is still in developement. Regarding different structure and condition, many different theories are put forward. A lot of experimental results indicate that stability of spacer grid has following features:

- Elastic buckling, also testified by our later analysis;
- Global buckling, not to be local wrinkle;
- Buckling of multi-element structure (made up of thin plate, beam and spring)
- Branch buckling.

In a word, stability of spacer grid is linear elastic, global and branch buckling problem. Static equilibrium method is applied in analysis for convenience of using general finite element computer code. The process of static equilibrium method is:

① Initial solution of static internal force in the structure

(1) $$[K]\{\delta_0\}=\{P_0\}$$

Here, $[K]$—structural stiffness matrix
$\{\delta_0\}$—displacement vector
$\{P_0\}$—Load vector, generally stands for unit Load.

$\{\delta_0\}$ can be available by solving eq (1) when $[K]$and $\{P_0\}$ are known, and subsequently all the static internal forces are obtained.

② Calculation of buckling modes and critical load

(2) $$([K_b]+\lambda[K_g])\{\delta\}=0$$

Here, $[K_b]$—structural stiffness matrix when buckling. $[K_b]=[K]$ if deformation is small.
$[K_g]$—geometrical stiffness matrix corresponding to load vector $\{P_0\}$.
λ—load factor
$\{\delta\}$—buckling displacement vector, buckling mode.

After λ and $\{\delta\}$ are obtained by solving eq(2), critical load $\{P_{cr}\}=\lambda\{P_0\}$

2.2 *Calculation of buckling modes and critical load*

- Finite element moclel of structure

All grid cell plates are modelized by plate element. The fuel rod and guide thimbles modelized by beam element. The dimples and spring clip are considered by the use of spring element or equivalent beam element. So the whole model of spacer grld is composed of plate elements, beam elements and spring elements.

Element mesh density is decided based on that the relative error of critical load is less than 1%.

- Boundary condition

Figure 1 shows the force acting on grid and boundary condition. spacer grid is placed on rigid base to restrict global displacement (translate and rotation). To simulate real loading condition of structure, two reseraint cases are considered: A, the loaded surface of structare is completely free; B, the loaded surface is restricted laterally. corresponding to them, two groups of results about buckling modes are given.

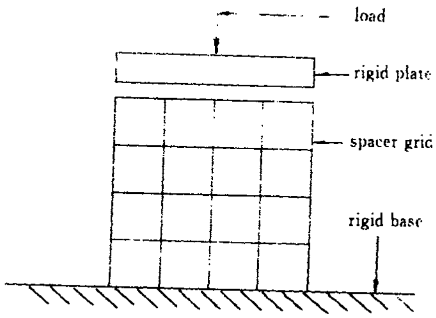

figure 1 boundary condition of structure

• Load

External load acting on spacer grid generally caused by crush of other spacer grid or rigid plate and its features are:

① nonuniformly distributed.

② existence of gap between spacer grid and loading body,

③ Value and distribution pattern of load are changed with the increase of load and deformation of spaeer grid.

A particular stiffness transform method is applied in this paper to settle the problem successfully. The load acting on spacer grid is selected as uniformly distributed unit load. The stiffness of cell plate acting as loaded surface is assumed to be large enough to surpass excessively the stiffness of other cell plate. Stress arising from bending moment in these plate are neglegible comparing with membrane stress. The loaded surface remains plane all the time to simulate crush of rigid body. For that purpose, material elastic module of the plate subjected to load is increased propriately. In this way, there will be not only simple calculation and clear concept and also reduction of sensitivity to loading error in buckling analysis.

3 RESULTS

3. 1 *stiffness*

4×4 grid: external stiffness Ke=186440 N/mm
internal stiffness Ke=11926 N/mm
17×17 grid: external stiffness ke=140700N/mm
internal stiffness Ki=187135N/mm

3. 2 *Buckling modes and critical loads*

Buckling modes of 4×4 grid are shown in figure 2.
Buckling modes of 17×17 grid are of the same shape as that of 4×4 grid
Table 1 gives the critical loads of spacer grid.

3. 3 *Mechanical characteristics of spacer grid versus each compound of grid.*

External stiffness of grid versus thickness of cell plate are shown in figure 3.
External stiffness of grid versus stickness of spring clip are shown in figure4.
Critical load of grid versus thickness of cell plate are shown in figure 5.
Critical load of grid versus stiffness of spring clip are shown in figure 6.

Table 1 Critical loads of spacer grid

mode	critical load (N)			
	4X4 grid		17X17 grid	
	uninserted rods	inserted	rods uninserted rods	inserted rods
A−1	4832	5437	15487	18045
A−2	5839	6573	15803	18729
A−3	7381	8122	16259	18858
A−4	8883	9573	16885	19350
B−1	5834	6573	15803	18279
B−2	7184	7848	16182	18824
B−3	8823	9499	16885	19350
B−4	15497	17279	17605	20183

4 Concluding remarks

From analysis discribed above, it is concluded that the buckling analysis method presented in this paper is feasible. Modern stability theory indicates that application of elastic global branch buckling theory to stability of structure featuring plate is safe. The analytical method will play an active role in the research and design of fnel assembly. Relevant figures and tables are supplied for reference.

Under shock, there are perturbations for high loading speed (even larger than speed of stress wave). Instability of structure is frequently in the form of high order buckling mode and corresponding buckling load is more than stactic value .

Comparing with beam or plate, the buckling modes of grid are of the same styles as that of them, but the critical loads are very different. The more the number of grid cell is, the less the interval of critical loads between two neigbbouring modes. So it is quite possible for the high order buckling mode to occure.

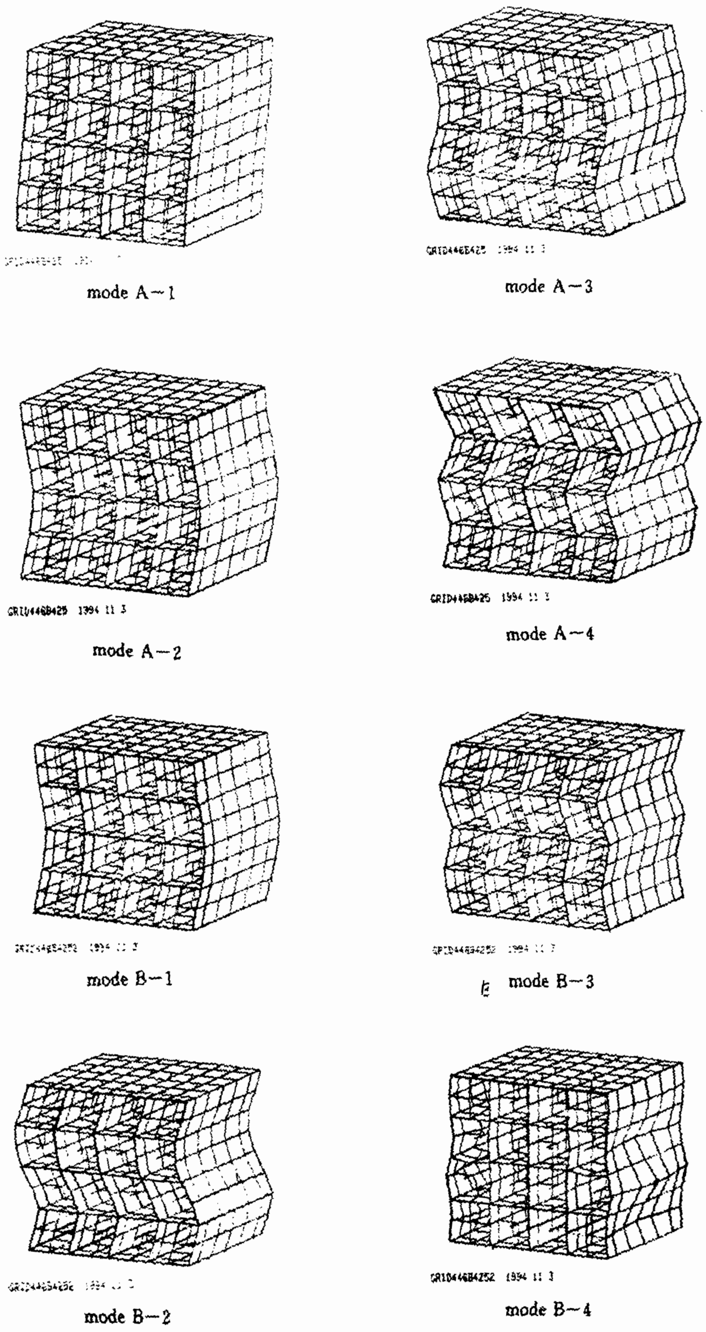

figure 2 . Buckling modes of 4×4 spacer grid

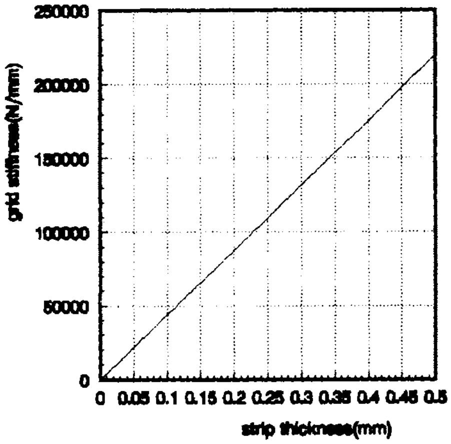

figure 3. External stiffness of grid versus thickness of cell plate

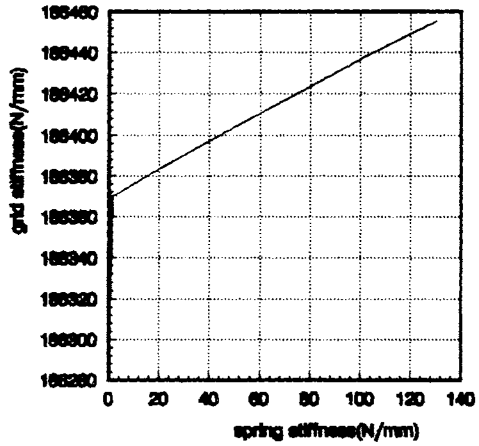

figure 4. External stiffness of grid versus stickness of spring clip

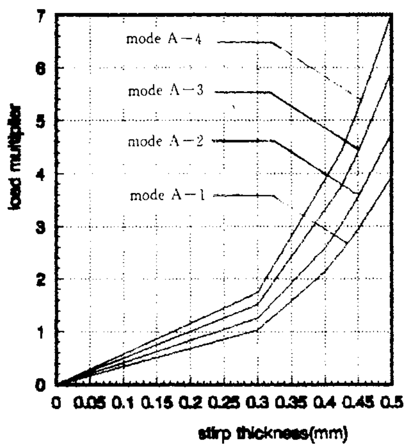

figure 5. Critical load of grid versus thickness of cell plate

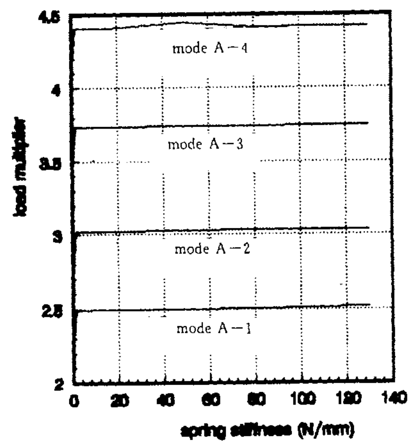

figure 6. Critical load of grid versus stiffness of spring clip

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