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The Dynamic Evaluative Method of Buckling Load Analysis of Oilfield Derrick

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Abstract: In this paper, a dynamic evaluative method is provided to define the buckling load of oilfield derrick. Firstly, the linear relationship between the basic frequency and the axial load of the cantilever structure with axial loading is solved (or determined) from the dynamic eigenvalue equation of the structure. Then, the load of oilfield derrick can be loaded step by step, and the basic frequency ω_{1i}^2 corresponding to the load N_i can be calculated or measured out, the linear relationship of $\omega_{1i}^2 \sim N_i$ is drown up using the data mentioned above. The axial force corresponding to $\omega_{1i}=0$ is the required buckling load of oilfield derrick. The suggested method may evaluate the buckling load of oilfield derrick combining nondestructive testing with calculating. It is convenient to estimate the bearing capacity of oilfield derrick.

Key words: buckling load; derrick; dynamic evaluation

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Introduction

Oilfield derrick is a large and complicated metal rigid-framed structure, it is one of the important equipment in the oil industry and plays an important role in oil production. So, it is of momentous practical significance to define the bearing capacity and give an evaluative standard of the reliability for the oilfield derrick. Nowadays, the standard of use permit and out of service of oilfield derrick is usually established based on experience not on full mechanical analysis, this can cause unnecessary waste or threaten the security of production. Furthermore, it is not actual to determine the buckling load directly by the method of destructive testing because of the huge body and the bearing heavy loading of the oilfield derrick. Therefore, it is necessary to search a convenient and practical method which combines nondestructive testing with calculating and computer simulating to estimate the buckling load of oilfield derrick.

Based on the facts mentioned above, a dynamic evaluative method is provided in this paper to define the buckling load of oilfield derrick.

1 Formulation of the Equation

For the cantilever structure shown in Fig.1, its flexural stiffness is EI and its mass per unit of length is $\bar{m}$, it is subjected to a constant vertical load N acted on the top. To approximate the motion of this system with a single degree of freedom, it is necessary to assume that it will deform only in a single shape. The shape function will be assumed as

$$\psi(x) = 1 - \cos\frac{\pi x}{2l}, \quad (1)$$

and the amplitude of the motion will be represented by the generalized coordinate $z(t)$, thus

$$v(x) = \psi(x) z(t). \quad (2)$$

The equation of motion of this generalized system can be formulated conveniently using Hamilton's principle[1,2]

$$m^* \ddot{z}(t) + \bar{k}^* z(t) = 0, \quad (3)$$

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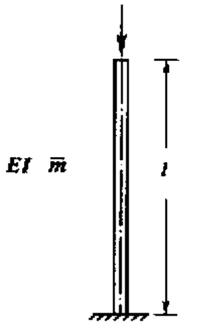

Fig.1　The cantilever structure

in which, generalized mass

$$m^* = \int_0^l \overline{m}\psi^2(x)\,\mathrm{d}x = 0.228\overline{m}l\ , \qquad (4)$$

generalized stiffness

$$k^* = \int_0^l EI(\psi''(x))^2\mathrm{d}x = \frac{\pi^4}{32}\frac{EI}{l^3}\ , \qquad (5)$$

generalized geometric stiffness

$$k_G^* = \int_0^l N(\psi'(x))^2\mathrm{d}x = \frac{N\pi^2}{8l}\ , \qquad (6)$$

Combined generalized stiffness

$$\bar{k}^* = k^* - k_G^* = \frac{\pi^4}{32}\frac{EI}{l^3} - \frac{N\pi^2}{8l}\ . \qquad (7)$$

Therefore, the equation of motion including axial force effects becomes

$$0.228\overline{m}l\ddot{z}(t) + \frac{\pi^4 EI}{32l^3}\left(1 - \frac{N}{\pi^2 EI/(4l^2)}\right)z(t) = 0\ , \qquad (8)$$

and the square of the basic frequency of system is

$$\omega_1^2 = \frac{\pi^4 EI}{7.296\overline{m}l^4}\left(1 - \frac{N}{\pi^2 EI/(4l^2)}\right)$$
$$= 13.2\frac{EI}{\overline{m}l^4}\left(1 - \frac{N}{\pi^2 EI/(4l^2)}\right)\ , \qquad (9)$$

Eq.(9) represents the linear relationship between the square the basic frequency ω_1^2 of the cantilever structure and the vertical axial force N, which proves that the basic frequency corresponding to the classical load can be used in evaluating the buckling load of ollfield derrick in nondestructive testing. The same conclusion can be obtained for any other structure. In this paper, the two dynamic evaluative methods of buckling load analysis of oilfield derrick are presented as follows.

1.1　Testing method

Two vibration tests are conducted without and with axial load N, with getting the basic frequencies ω_{10} and ω_{11} of the structure, respectively. Based on the two groups of actual datum, the linear relationship between ω^2 and N can be obtained.

According to Eq.(9) the load corresponding to $\omega_1 = 0$ is the buckling load N_{cr} of oilfield derrick. To increase the precision of testing results, many different load N_i can be applied one by one and several tests may be done corresponding to each N_i. Finally, the mean value can be taken as the critical buckling load of oilfield derrick.

1.2　Computer simulation method

Firstly, the dynamic eigenvalue equation of oilfield derrick with axial load N acted on the top is

$$|\,[K] - \lambda_g[K_g] - \omega^2[M]\,| = 0\ , \qquad (10)$$

in which, $[K]$, $[K_g]$ and $[M]$ are stiffness matrix, geometric stiffness matrix and mass matrix of oilfield derrick finite element model, respectively. The relationship between the square of the basic frequency ω_1^2 of oilfield derrick and axial load N is solved by computer simulation. When $\omega_1^2 = 0$, the generalized eigenvalue λ_g given in Eq.(10) is the required buckling load of oilfield derrick. In practice, the load of oilfield derrick can be loaded step by step and the basic frequency ω_{1i}^2 corresponding to the steped load N_i can be calculated out, using the relationship between ω_1^2 and N_i, then the load corresponding to $\omega_1 = 0$ is the buckling load of oilfield derrick.

In order to increase the calculation precision, the two methods mentioned above can be combined to use. Firstly, the relationship between ω_1^2 and N_i is presented with computer simulation. Next, the relationship between ω_1^2 and N_i is modified by the model testing of oilfield derrick. Finally, let $\omega_1^2 = 0$, the load corresponding to $\omega_1 = 0$ is the required buckling load of oilfield derrick.

2　Numerical Examples

Example 1. A cantilever structure is shown in Fig.1, both flexural stiffness EI and mass per unit of length $\overline{m}$ of the structure are uniform distribution along its length.

The structure is discretized by dividing it into 3 elements by finite element method and loaded step by step. Using Eq.(10), the relationship between the basic frequency ω_1^2 and axial load N_i acted on the top of the structure is shown in Fig.2. Then the load corre-

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sponding to $\omega_1 = 0$ is the buckling load N_{cr} of the cantilever structure, as follows:

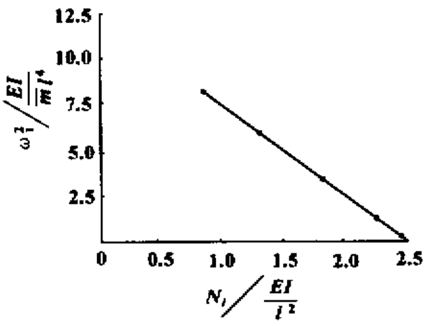

Fig.2 The $\omega_1^2 \sim N_i$ curve of the cantilever structure

$$N_{cr} = 2.44 \frac{EI}{l^2} . \tag{11}$$

The true buckling load P_{cr} of an uniform cantilever structure is theoretically[3]

$$P_{cr} = \frac{\pi^2 EI}{4l^2} . \tag{12}$$

The results of both Eq.(11) and Eq.(12) are approximately equal, the calculating error is 1.1%.

Example 2. A plane frame structure is shown in Fig.3, the flexural stiffness EI, mass per unit of length $\bar{m}$ and length l are all constant.

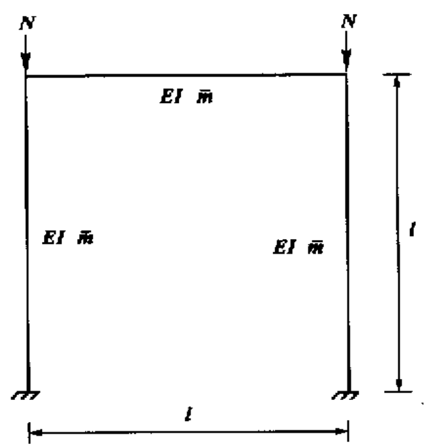

Fig.3 The plane frame structure

The structure is idealized by finite element method, every bar is divided into 2 elements, loading on the top of plane frame, using Eq.(10) the relationship between the square of the basic frequency ω_1^2 and axial load N_i acted on the top is shown in Fig.4.

Based on the relationship between ω_1^2 and N_i, the vertical load corresponding to $\omega_1 = 0$ is the required buckling load N_{cr} of the structure, has

$$N_{cr} = 7.40 \frac{EI}{l^2} , \tag{13}$$

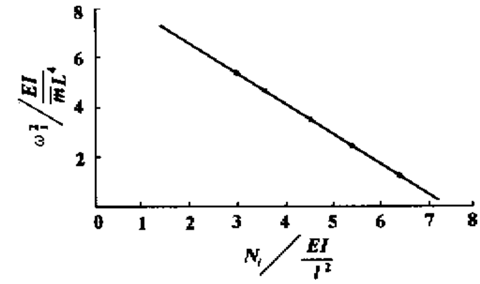

Fig.4 The $\omega_1^2 \sim N_i$ curve of the plane frame structure

The true buckling load P_{cr} of this plane frame is theoretically[3]

$$P_{cr} = 7.34 \frac{EI}{l^2} . \tag{14}$$

The results of both Eq.(13) and Eq.(14) are approximately equal with a calculating error of 0.8%.

It is known through the two examples above that the result of the method presented in this paper is identical to the result of the theory method. So the theory of this paper is correct and the method is reliable. It can be used in the engineering for buckling load analyses.

3 Application of Engineering

The bearing capacity of a using oilfield tower derrick is estimated by the method of this paper. The derrick is a quadrilateral space frame metal structure, the horizontal plane size of the bottom of the structure is 12 m × 12 m, the top size is 3 m × 3 m, the highness of the derrick is 48 m. This paper simplifies the derrick as 86 space beam elements and 31 nodes, Fig.5 is the calculating model of the structure.

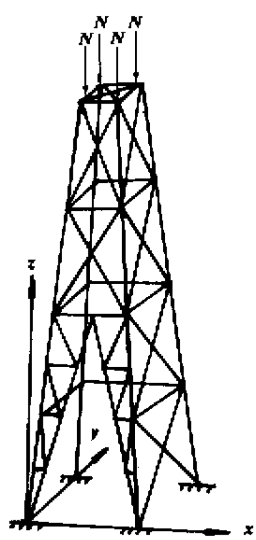

Fig.5 Calculating model of oilfield tower derrick

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Loading on the top of the derrick, using Eq.(10), the relationship between the square of the basic frequency ω_1^2 and axial load N_i is shown in Fig.6. Based on the curve $\omega_1^2 \sim N_i$ of Fig.6, the axial load corresponding to $\omega_1 = 0$, that is, the buckling load of the oilfield tower derrick $N_{cr} = 1249$ kN.

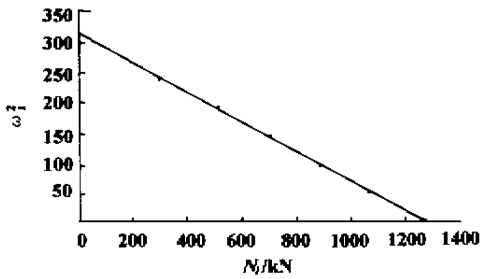

Fig.6　The $\omega_1^2 \sim N_i$ curve of the oilfield tower derrick

4　Concluding Remarks

A dynamic method for evaluating the buckling load of oilfield derrick is provided in this paper, which may combine nondestructive testing with calculating. Its operation is convenient and needs less equipment than the traditional method of static test, the result of this method is identical to that of the traditional method. So, it is a practical and valuable method for evaluating the buckling load of oilfield derrick. A new way is operated for estimating the bearing capacity of structure quantitatively, which can also be used to estimate the buckling load of other engineering structures.

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钻井井架屈曲荷载分析的动态评估方法

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摘　要：提出一种确定石油钻井井架结构屈曲荷载的动态评估方法.其基本思想是:首先利用井架结构的特征值方程建立井架结构的基本固有频率和其所承受竖向轴向力的关系;然后，对井架结构分级加载，计算或实测出井架结构的各级荷载 N_i 所对应的基本固有频率 ω_{1i}，由此可以得出井架结构基本固有频率 ω_{1i}^2与所承受荷载 N_i 的变化关系曲线，相应于 $\omega_{1i}^2 = 0$ 时所对应的轴向力即为所求井架结构屈曲荷载.所建议方法可以与井架结构非破坏性试验相结合来确定井架结构的屈曲荷载，它是石油钻井井架结构承载能力评估的实用方法.

关键词：承载能力；井架结构；动态评估

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