

Fatigue Reliability Analysis on the Concrete Beams

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Abstract—Concrete beams fatigue damage is mainly a problem in practical engineering , the fatigue failure mechanism than the destruction of the static bearing capacity mechanism is complex and influenced by many factors , a large number of experimental data shows that the fatigue life of the concrete beam is random , the need analyze the use of probability theory and reliability theory .Based on the theories of the fatigue life prediction using ANSYS finite element analysis software to establish concrete beam finite element model for fatigue reliability analysis , the results explain that the stochastic finite element method analysis of fatigue is very practically.

Keywords-concrete beams; ANSYS; fatigue damage ; reliability analysis

I. INTRODUCTION

The concrete material is the most widely used building materials in current projects , made by pouring concrete structure or component to withstand the static load but also by an increasing number of repeated load . Common concrete beams during service , to experience the working load , extraordinary loads , occasional loads (such as hurricanes, earthquakes , etc.) , the role of crowd loading , but also subjected to various environmental factors , such as sunshine, temperature, freezing and thawing , wind, frost, rain and snow , erosion and invasion of this type of load characteristics is the time back and forth with the role of the structure when the number of loads or effect long enough , the damage occurred is the fatigue damage . The essence of fatigue failure of concrete beam structure of the internal damage to accumulate , making it lower , it is a brittle failure . However, due to the concrete beams in which the environment and materials inherent in the discrete and other reasons , even under the same experimental conditions , the same specimen in the role of the loading process of the same uncertainty , the fatigue life there are very discrete .Fatigue failure of the law , we can not be determined , but the introduction of probability theory and reliability theory based on the S-N curve for fatigue life analysis, to calculate the failure probability of fatigue failure of concrete beams , the method makes the study of the fatigue problem is more precise[1] .With the help of finite element analysis software ANSYS Fatigue (fatigue) and PDS (probabilistic design) module , use the the APDL advanced parameterized language.

For example, a cantilever beam bending fatigue test data on the basis of concrete beams under constant amplitude fatigue loading fatigue analysis using Monte Carlo (MC) random

reliability analysis method is simple to calculate faster , saving resources for the engineering design provides a convenient estimation method .

II. FATIGUE DAMAGE OF CONCRETE BEAMS

Fatigue failure of the concrete beam is gradually accumulated inside the material damage process , this cumulative process is usually irreversible and random energy dissipation process , so the correct description of the material subjected to cyclic loading , fatigue damage accumulation process of development , the material fatigue life estimates, to carry out anti-fatigue design and reasonable structure. Currently, the engineering community widely used fatigue cumulative damage theory is completed and Miner 's linear cumulative damage theory proposed by Palmgren , reference to the structural reliability analysis on the probability Miner theory , the theoretical answer the materials of engineering structures under fatigue loading internal fatigue damage accumulation process and the fatigue failure criterion .The use of Miner theory is based on the traditional stress - life curves , SN curves to determine whether the structure of failure, while the description of the empirical equation of the SN curve , we used the regression equation of the exponential function by the experimental data is often said fatigue equation :

$$Ne^{\alpha S} = C \quad (1)$$

where α and C for the material constants determined by experiments , S is the stress level , the general stress amplitude , where the fatigue analysis of the third strength theory of fatigue stress , N for the life of the structure of the mean stress level . on both sides of the logarithmic , and finishing a double-logarithm fatigue equation :

$$\lg N = a + bS \quad (2)$$

Where a and b are material constants , through the experimental data .

Miner theory under cyclic loading , fatigue damage can be linearly additive , various stress independent and unrelated , the specimen or component occurs when the cumulative damage reaches a certain value , the fatigue failure .Injury criteria are as follows :

$$D = \sum_{i=1}^k \frac{n_i}{N_i} = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \dots + \frac{n_k}{N_k} \quad (3)$$

Where : D is the cumulative damage of the material (or construction details).By (3) single-stage constant amplitude cyclic loading , fatigue damage of concrete beam as follows:

$$D = \frac{n}{N} \quad (4)$$

According to Miner's rule[2] , when the total damage amount D accumulated to greater than or equal to the critical injury in the amount of Dc (general Dc = 1) , that the structure destruction :

$$D \geq D_c = 1 \quad (5)$$

III. RELIABILITY ANALYSIS OF MODEL

Any engineering structures require a certain degree of reliability , because the structure of a variety of influences in the process of design, construction and use of its safety , serviceability and durability uncertainties . Structural reliability analysis of the task is to consider the impact of various types of uncertainties on the structural analysis , and eventually to a quantitative (a reliable indicator) to describe the fatigue analysis , in order to more efficient use of Miner's Rule , the following will be reliable the theory of the introduction of the Miner's Rule , the establishment of the accumulated fatigue damage limit equation is as follows :

$$Z = D_c - D = D_c - \sum_{i=1}^k \frac{n_i}{N_i} = 0 \quad (6)$$

Where (6) in the reliability study can also be called a performance function , when the function Z>0 in a safe state ,when the function Z=0 in critical state , when the function Z<0 in the damage.After the introduction of reliability theory to the formation of the theory of probability Miner , critical damage Dc as a random variable , Dc as the performance of a material with material properties , loading sequence, the change of load level and other factors present complex , due to the Miner's Rule can better predict the mean life , so to take $\mu_{Dc} = 1$ standard deviation of the specific test to be determined [3] [4] .

A variety of concrete structures under fatigue experimental raw data , the discrete nature of the fatigue life of a great and must use the theory of mathematical statistics , combined with the reliability of the original theory to organize the raw data , to discover its internal law , under normal circumstances , the fatigue life N lognormal distribution , the distribution density function $f_N (n)$ for :

$$f_N (n) = \begin{cases} \frac{1}{\sqrt{2\pi}\sigma_N n} \exp\left\{-\frac{(\ln n - \mu_N)^2}{2\sigma_N^2}\right\} & n > 0 \\ 0 & n \leq 0 \end{cases} \quad (7)$$

D (n) is the lognormal distribution , the distribution density function :

$$f_D (d) = \begin{cases} \frac{1}{\sqrt{2\pi}\sigma_D d} \exp\left\{-\frac{(\ln d - \mu_D)^2}{2\sigma_D^2}\right\} & d > 0 \\ 0 & d \leq 0 \end{cases} \quad (8)$$

which: $\mu_D = \ln n - \mu_N$, for D logarithmic mean , $\sigma_D = \sigma_N$ for D is the number of standard deviation , that is, D is the intrinsic dispersion of the standard deviation of life standards the same .

Usually for the calculation and expression of convenience, the structural reliability analysis is also commonly used in structural failure probability to measure the reliability of the structure of Z for random impact factors performance function can be expressed as Z (X) . the probability of failure is :

$$P_f = P[Z(X) < 0] = \int_{Z(X) < 0} f(x) dx \quad (9)$$

Where f (x) is the joint probability density function of random variables .

The reliability of the structure : $P_s = 1 - P_f$, a reliable indicator of the structure :

$$\beta = \Phi^{-1}(1 - P_f) \quad (10)$$

Where $\Phi (\bullet)$ - the standard normal probability distribution function .Here for structural reliability analysis method , the first order second moment method , the second second-order moment method , Monte-Carlo numerical simulation method , probabilistic finite element method[5] .

IV. APPLICATION EXAMPLES

A concrete cantilever beam finite element model shown in Figure 1,Strength grade of concrete using C30,bending fatigue test data derived from "the flexural fatigue cumulative damage properties of a text "(author Li yongqiang , Che Huimin) , fatigue equation derived from"concrete fatigue characteristics of a text" (author Zhang Wei),C30 concrete flexural strength 11.59Mpa,Bending fatigue equation is:lgS=0.0486-0.0444lgN,elastic modulus of concrete e=3E4Mpa,Poisson's ratio $\nu=0.2$,density $\rho=2500\text{kg/m}^3$,beam width high are the same B=250mm,length L=2500mm,maximum load to withstand uniform P=0.05Mpa,minimum load for 0,the cantilever design cycle times for 4e5,assume $\sigma_{Dc}=0.1$,Statistical characteristics of the various parameters in Table 1[6][7].

Table1 statistical properties of a random input variable

Random variables	unit	mean	variance	lower limit	up limit	distributio n type
e	Mpa	3E4	1.5E3			GAUSS
ρ	mm			1250	3750	UNIF
B	mm			B-0.1	B+0.1	UNIF
L	mm			L-0.1	L+0.1	UNIF
Dc		1	0.1			LOG2

A. *eight-node hexahedral elements to simulate the concrete cantilever beam , the finite element mesh model diagram and the stress intensity diagram is shown below :*



Figure1 Finite element model diagram

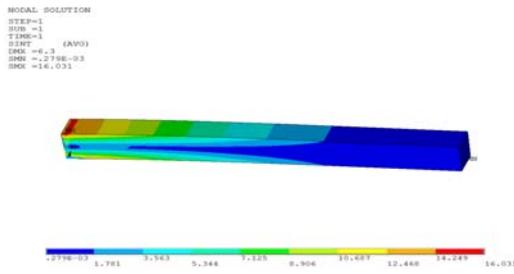


Figure 2 Stress intensity map

B. Select the maximum stress MAXSTRESS fatigue life N , fatigue damage D , the performance function Z is the output variable, using the MC method, Latin Hypercube random sample of 5000.

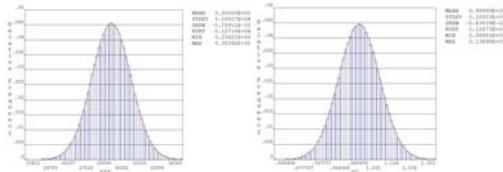


Figure 3 e, Dc histogram

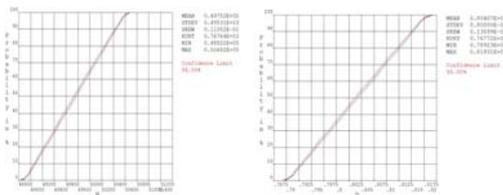


Figure 4 N, D cumulative distribution function map

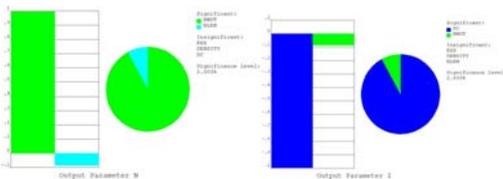


Figure 5 N, Z the probability of sexual sensitivity

By the probability histogram of the design results can be seen, close to the elastic modulus e and D_c discrete probability function curve, relatively smooth and there are no major gaps, we can see that the random variable changes the situation stabilized, indicating that the simulation of a sufficient number the results of convergence, more accurate analysis of the probability of failure and reliable indicators. A random variable of mean, standard deviation, skewness, peak data sets as well as extreme value related data can be extracted from these figure, but also calculate the life N the logarithm of the mean $\mu_N = 10.815$ logarithmic deviation $\sigma_N = 0.00996$, the logarithm of the mean of the damage D is $\mu_D = -0.218$, logarithmic deviation $\sigma_D = .00996$, the logarithmic mean value into the formula $\mu_D = \ln n - \mu_N$, draw $-0.218 = \ln 40000 - 10.815$ just to satisfy the formula, and $\sigma_N = \sigma_D$, we can see N, D , are subject to the lognormal, in accord with probabilistic Miner's Rule, and the maximum stress MAXSTRESS fatigue life N , the fatigue damage D kurt (peak) of data sets is almost the same. Probability sensitive graph shows, the most sensitive

factor affecting the fatigue life N is a sectional dimensions of the concrete beams and wide (The width equal), and is a positive relationship between the two fitting coefficients 0.9950, affect the performance function Z of the most sensitive factors need to be determined by experiment, D_c scatter plot shows the D and section size of an inverse relationship with changes in fatigue life is the opposite, in line with the Miner theory. The same time, the probability calculation results show that the failure probability of 2.5548%, 97.4452% reliability, a reliable indicator of $\beta = \Phi^{-1}(1 - P_f) = \Phi^{-1}(0.974452) = 1.95$, In addition, the cumulative distribution function in Figure query failure probability of fatigue life and damage.

V. CONCLUSION

(1) Miner's theory can be used to estimate the mean life of the concrete beams, random sampling method with MCS is a manifestation of the theory of probability Miner, the sampling results show that the distribution of N and D correspond to the theory of probability Miner, then the stochastic finite element method in fatigue the practicality of the problem.

(2) By the results of probabilistic design sensitivity, scatter shows that the cross-section dimensions of concrete cantilever beam is wide and high impact on the fatigue life is proportional to the relationship, followed by the length of the concrete beams, but the fatigue life and the length of an inverse relationship, damage on the contrary, in order to ensure the reliability of the concrete beams to meet the requirements of reasonable option sectional dimension is the key.

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