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Analysis of creep process of marine concrete

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Abstract. The use of marine concrete is increasingly common with the rapid development of marine economy. The corrosion and fracture of concrete in marine building structures are relatively serious, due to the strong corrosiveness of sodium and chlorine ions in seawater. Therefore, it is of great significance to study the creep laws of concrete in marine environment. A marine concrete pier is taken as the analysis object, and the elastic theory and concrete creep theory are combined to build a model of that. The creep curves of concrete in marine environment are obtained by using finite element method, and it can be compared with the creep curves of ordinary concrete in theoretical analysis. The results show that the stress relaxation of marine concrete is greater and the stress state is more unstable than that of ordinary concrete under the same conditions. The time for marine concrete to reach the same stress state is about 6-9 years earlier than that of concrete in normal environment. In addition, it takes a longer time for the stress state of marine concrete to tend to be stable.

1. Introduction

In recent years, there are more and more concrete buildings in the marine environment, and the buildings of our country are facing severe durability problems. Some concrete buildings in coastal areas, affected by marine climate and seawater corrosion, suffer from different degrees of corrosion damage, which not only needs to invest a lot of time for maintenance and renovation, but also causes huge economic losses to the country. Therefore, the study of the changing law of concrete with time in marine environment will help to reduce the aging and damage of marine building structures, and has important social significance for the development and protection of marine resources[1].

A concrete bridge pier is taken as an analysis object to study the change of marine concrete performance with time. By consulting relevant documents and codes, and counting the length, width and thickness of the deck of the whole sea-crossing bridge, the uniform load on each pier is estimated, and the appropriate concrete strength and reasonable reinforcement ratio are selected. The pier structure is analyzed by the software ANSYS, and the concrete properties and creep curves in marine and common environment are obtained. In addition, the stress and deformation diagram in all directions of the structure are calculated.

2. Calculation principle

2.1. Test results of creep of concrete

Creep refers to the phenomenon that the strain of concrete grows slowly with time under constant stress, which is also the result of time effect. However, with the accumulation of time, the stress of the material also changes. Therefore, the generalized concept of concrete creep can be concluded as a phenomenon that the stress and strain of concrete members change with time when subjected to a constant force. The test found that the creep deformation of concrete may reach 1~2 times of the elastic deformation, or even more. At the same time, stress and strain are not corresponding and they have irreversible properties. The initial creep test was carried out only under the action of unidirectional stress. According to the initial test data and results[2], a typical creep curve can be drawn, as shown in the following figure.

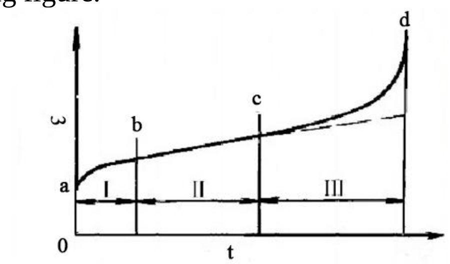

Figure 1. Creep relation curve

2.2. Creep theory

The creep behavior is simulated by an equation, which describes the main characteristics of creep (especially in one-dimensional stress state). This equation is expressed in terms of creep strain rate, and its form is as follows:

$$\overset{.cr}{\varepsilon} = A\sigma^{B}\varepsilon^{c}t^{D} \tag{1}$$

Where A, B, C, and D are material constants obtained from experiments, and these constants may also be a function of stress, strain, time or temperature. This form of equation is called the equation of state. When the constant D is negative, the creep strain rate decreases with time and the material is in the initial creep stage. When D is 0, the creep strain rate is constant and the material is in the second creep stage. For two-dimensional or three-dimensional stress states, VON Mises equation is used to calculate scalar equivalent stress and equivalent strain used in creep strain rate equation. When integrating the creep equation[3], the modified total strain is adopted, and its expression is:

$$\left\{\varepsilon_{\mathrm{n}}^{t}\right\} = \left\{\varepsilon_{\mathrm{n}}\right\} - \left\{\varepsilon_{\mathrm{n}}^{pl}\right\} - \left\{\varepsilon_{\mathrm{n}}^{th}\right\}\left\{\varepsilon_{\mathrm{n-1}}^{cr}\right\} \tag{2}$$

Next, the elastic strain and the total creep strain can be calculated according to the following formula (taking the component in the x direction as an example)

$$(\varepsilon_{\mathrm{x}}^{el})_{n} = (\varepsilon_{x}^{t})_{n} - \Delta\varepsilon_{x}^{cr} \tag{3}$$

3. Finite element calculation

3.1. Establishment of finite element model

The research object is an oval pier with a height of 35m, and the upper and lower bottom surfaces are composed of two semicircles with a radius of 1.5m and a rectangle with a length of 7m and a width of 3m, as shown in figure 2. In this example, the model is meshed by mapping to obtain regular cell shapes to improve the accuracy of analysis and convergence of calculation. Two semi-cylinders and cuboid columns are meshed respectively, to make their partition specifications identical, and the partition structure at the interface is completely identical after the grid division, so as to ensure the transfer effect of the applied load.

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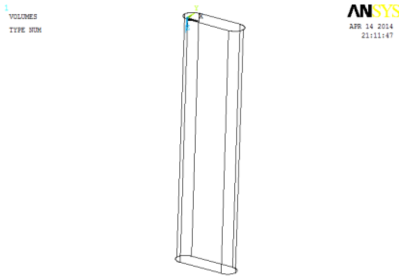

Figure 2. Solid geometry model

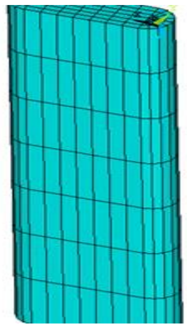

Figure 3. Finite element entity model

3.2. Calculation Parameters

The combined finite element model is selected in this example. It is believed that the steel bar and concrete are fully engaged and there is no relative slip between them. The unit SOLID65, a special concrete unit in ANSYS, was used for simulation. The basic material parameters of concrete are defined, and the elastic modulus of concrete is calculated by empirical formula. After calculation, the elastic modulus of concrete is 28562 N/mm^2. In addition, Poisson's ratio of concrete is 0.24. The constitutive relation of concrete is simplified from a three-dimensional model to a one-dimensional model in ANSYS. We only need to define the stress-strain curve of concrete under uniaxial compression. The stress-strain relation of concrete is established, and the constitutive relation curve of concrete is drawn automatically by ANSYS, as shown in the following figures.

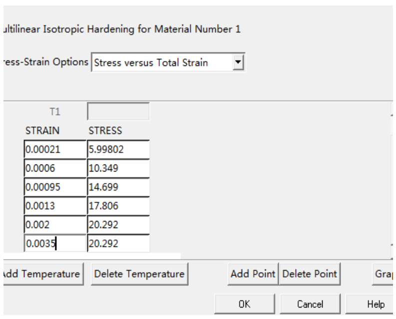

Figure 4. Stress-strain relationship

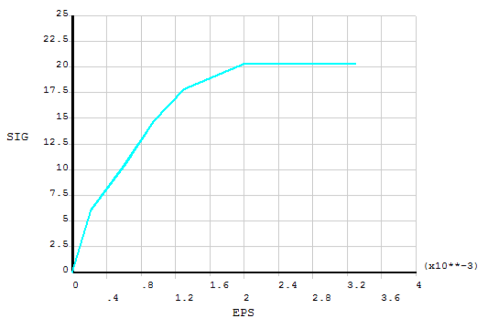

Figure 5. Constitutive relation curve

3.3. Calculation process

First of all, displacement conditions should be added to the pier model, that is, displacement load should be applied, and the degree of freedom of the bottom surface of the pier is completely constrained. When defining the coordinate axis, the length direction of the pier is the X axis, the width direction of the pier is the Y axis, and the height direction of the pier is the Z axis. The loading area is the entire plane at the top, and the dead weight of the structure is regarded as vertical load. According to the concrete specification, the equivalent stress of the calculated load is 0.4MPa. The ANSYS program automatically investigates and determines the time step based on the characteristics of the structure and the response of the system, and the loading time is set to 47 years. The required time step is adjusted by activating the automatic time step to obtain a good balance between accuracy and calculation time. At the same time, the temperature is set to 10℃. The coefficient determined by the creep of concrete introduced earlier is input, and then the model is solved.

4. Calculation results

4.1. Analysis of creep strain results

Under the action of dead load for 47 years, the creep strain results of concrete piers in marine environment are shown in the following figures. As can be seen from the figures, the creep of concrete

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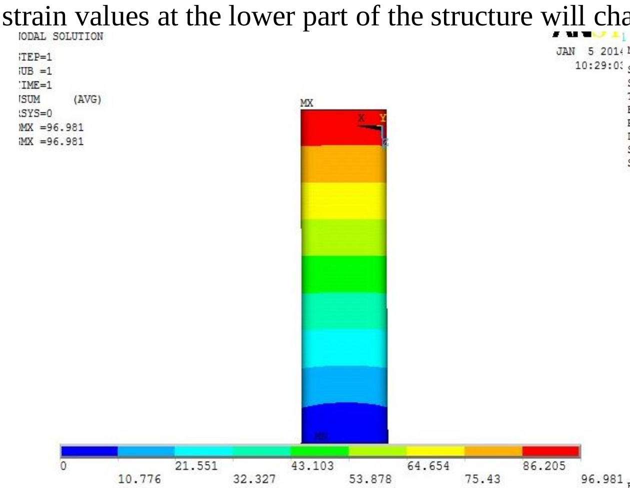
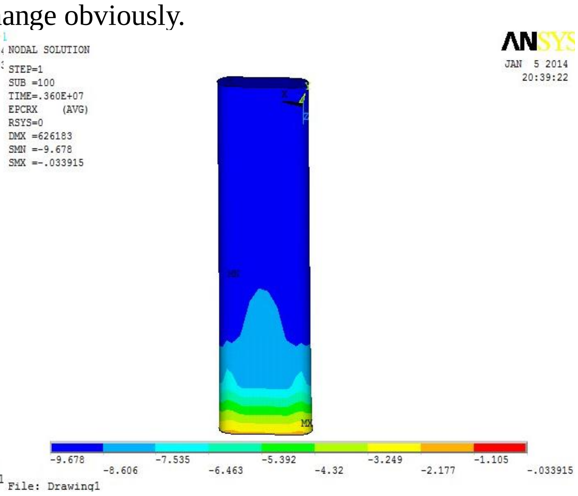
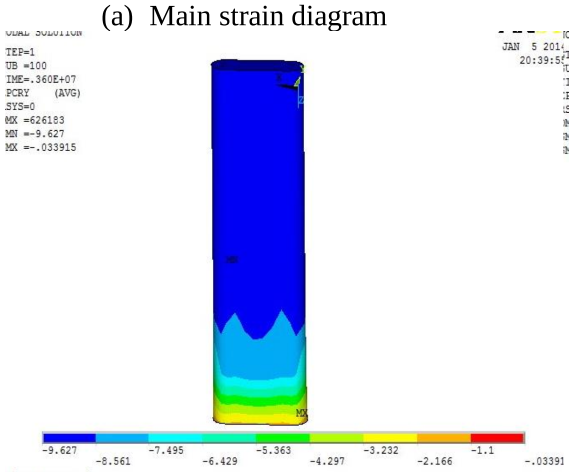
has obviously changed the mechanical properties of the structure, causing stress redistribution within the component. Generally speaking, the creep strain values of the middle and upper parts of the structure are basically the same. In the lower part of the structure, the creep strain value changes with different positions, and the lower the strain value is, the smaller it is. Specifically, the creep strain laws in X and Y directions of the structure are basically the same, and the creep strain values are all negative, which conforms to the actual situation. In the Z direction, that is, the height direction of the structure, the creep strain value of the middle and upper part of the pier structure reaches 18.952, and the creep strain value of the bottom of the structure reaches 0.067. It can be seen that the creep strain values at different positions of the pier structure are not very different in either direction, but the creep strain values at the lower part of the structure will change obviously.



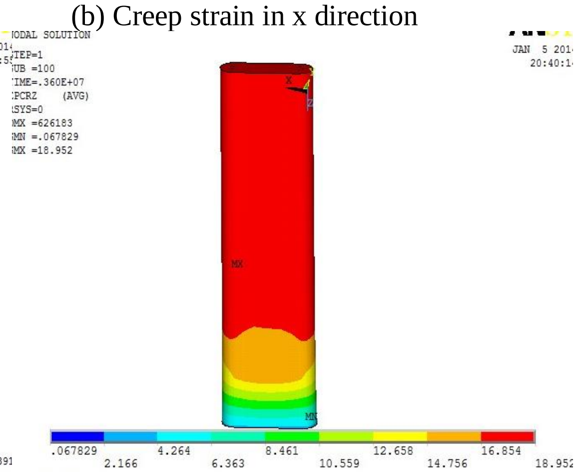
(a) Main strain diagram



(b) Creep strain in x direction



(c) Creep strain in Y direction



(d) Creep strain in Z direction

Figure 6. Results diagram of creep strain

4.2. Comparative analysis of two environments

The influence of seawater on concrete is mainly reflected in the chemical action of seawater, the physical action of repeated dry-wet alternation, and the crystallization and focusing of salt in concrete. In addition, it can also lead to steel corrosion. Therefore, there are great differences in various characteristics of concrete in the two environments. The comparison of stress relaxation of concrete in the two environments is shown in the following figure. As can be seen from figure 4, under the same conditions, the stress relaxation of marine concrete is larger than that of concrete under normal environment, which indicates that the corrosion of seawater to concrete and the influence of chloride ions on steel bars make the stress state more unstable. Compared with concrete in ordinary environment, the time for marine concrete to reach the same stress state is about 6-9 years earlier.

Moreover, the creep of concrete in the marine environment tends to stabilize for a longer time.

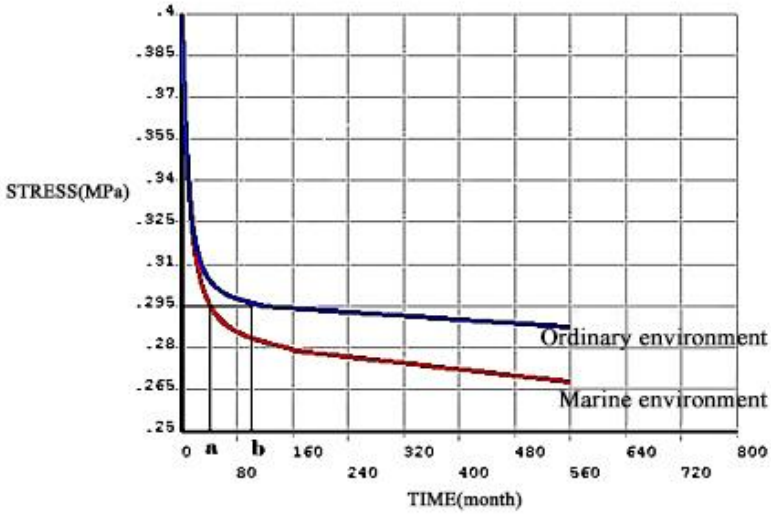


Figure 7. Contrast diagram of stress relaxation curves

5. Conclusions

(1) In the marine environment, the creep of concrete will significantly affect the mechanical properties of the structure, increase the deformation of the members, and cause the stress redistribution of the structural section. Therefore, in important hydraulic engineering, concrete creep test should be conducted according to the actual situation to understand the characteristics of material creep, so as to further avoid risks and improve safety and reliability.

(2) When the parameters are determined, numerical simulation can be used to replace some tests and save the manpower and material resources required for the tests. Moreover, it can predict the creep change for a longer time, which is of great significance to analyze the mechanical properties of concrete in marine environment.

(3) Compared with common environment, concrete structures in marine environment are more affected by creep. The stress state of the building structure in the marine environment is unstable, the stress relaxation is more obvious, and the time to reach the same stress state is earlier. In addition, it takes longer for concrete creep in the marine environment to stabilize.

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