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Seismic Analysis of Prestressed Bridge Pier Based on Fiber Section

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Abstract

Fiber model analysis method based on flexibility method is carried out to build analysis model for integral cast in-situ prestressed bridge piers, and the nonlinear time-history analysis is conducted with the low-peried cyclic loading. The hysteretic behavior of prestressed reinforced concrete pier and common reinforced concrete pier are compared and analyzed. The results showed that prestressed reinforced concrete pier has preferable re-centring capacity, smaller residual deformation and worse energy dissipation capacity. Along with the increase of distance from prestress location to section centroid, the tension degree of prestressed reinforcements and the reinforcement ratio come a decrease the residual deformation and energy dissipation capacity of pier.

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Keywords: prestressed concrete; piers; hysteresis loops; nonlinear analysis

In the Kobe earthquake in1995, about one-fifth common reinforced concrete piers whose damage is not serious needed reconstructed because of excessive residual plastic deformation. So after earthquake Japan made a strict stipulation for residual displacement in amended highway bridge seismic design specification that the residual rotation angle must be less than 1/100 radians. Therefore, international scholars made a mass of tests and theoretical researches[1] on high ductility and low-residual displacement pier.

Supported by the Japanese Prestressed Concrete Engineering Association, according to the disadvantages that low energy dissipation capacity and poor ductility performance of pure prestressed concrete pier and large residual plastic deformation of pure common reinforced concrete pier, Zatar and

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other researchers[2] put forward a assumption that mix use of common reinforcement and prestressed reinforcement in a pier. It is by vertical prestressed reinforcement to decrease residual plastic deformation of pier and by common reinforcement to increase ductility capacity, energy dissipation capacity and to control the crack of pier body.

Studies[3] [4] showed that by adopting tension prestressed reinforcement in common reinforced concrete pier, it can increase re-centering capacity of pier and decrease residual displacement of pier under earthquake excitation. And because of the low energy dissipation it would also increase the displacement demand. The major factors that affect the seismic behavior of integral cast in-situ prestressed bridge pier include tention degree, location and reinforcement ratio of prestressed reinforcement ect.

In this paper, adopting fiber model analysis method for integral cast in-situ prestressed bridge pier, analyzes nonlinear time-history and studies the impact and variation law of above factors on hysteretic behavior, ductility capacity and residual deformation of pie.

1. Analysis Model

1.1. Introduction to fiber model analysis method

Elastic-plastic fiber beam element is divided into many segments in axial, and the characteristics of each segment are represented by the intermediate cross section. Furthermore that cross section is discreted into many fibers. Different fiber in the same section can has different material properties. According to the plane section assumption and stress-strain relationship of material, the bending stiffness of each section could be calculated. By integrating along unit length, stiffness of elastic-plastic fiber beam element could be obtained [5] [6].

Basic assumptions of elastic-plastic fiber beam-column element include:

- (1) Small deformation assumption based on geometric linear.
- (2) Plane section assumption.
- (3) A beam element is divided into several integral segments. In each segment the section type and constitutive relation of each fiber keep consistent.
- (4) Neglect the impacts of bond slip and shear slip.
- (5) Consider that torsion is elastic and does not couple with bending moment and axial force.

1.2. Elastic-plastic fiber beam-column element based on flexibility method

Flexibility method is through establishing force interpolation function to the formation of element stiffness matrix. The best advantage is that it strictly meets the force equilibrium condition, and is not affected by the level influence of beam element material nonlinear state.

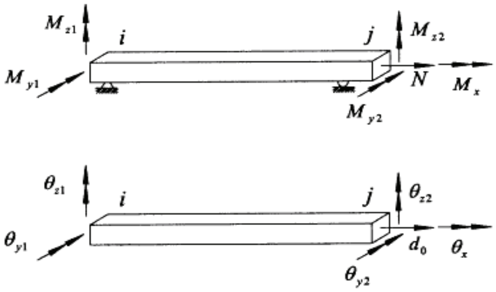


Fig.1 Element force and deformation without rigid modes in local reference system

Referring to Fig.1, elemental rod end force without rigid modes or torsion is

$$\{F\} = [M_{y1}, M_{y2}, M_{z1}, M_{z2}, N]^T \tag{1}$$

The static equilibrium equations show the section force of x-axial coordination

$$\{q(x)\} = [T(x)]\{F\} \tag{2}$$

$\{q(x)\} = \{m_y(x), m_z(x), p_0(x)\}$ .With the known element force, the $\{q(x)\}$ can be obtained through the element equilibrium equations .And the transfer matrix $[T(x)]$ is [7] [8]

$$[T(x)] = \begin{bmatrix} -(1 - x/L_0) & x/L_0 & 0 & 0 & 0 \\ 0 & 0 & -(1 - x/L_0) & x/L_0 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

The corresponding element rod end displacement without rigid modes or torsion is

$$\{D\} = [\theta_{y1}, \theta_{y2}, \theta_{z1}, \theta_{z2}, d_0]^T \tag{4}$$

$\{d(x)\}$ is the section deformation column vector of x-element coordination .On the basis of energy conservation, the internal force work should be equal to the external, that is

$$\{F\}^T \{D\} = \int_{L_0} \{q(x)\}^T \{d(x)\} dx \tag{5}$$

L_0 is the element length, and push (2) into (5), then

$$\{D\} = \int_{L_0} [T(x)]^T \{d(x)\} dx \tag{6}$$

The element flexibility matrix without rigid modes or torsion can be obtained by the virtual displacement principle or minimum potential energy principle.

$$[f_b] = \int_{L_0} [T(x)]^T [f(x)][T(x)]dx \tag{7}$$

The corresponding stiffness matrix is

$$[k_b] = [f_b]^{-1} \tag{8}$$

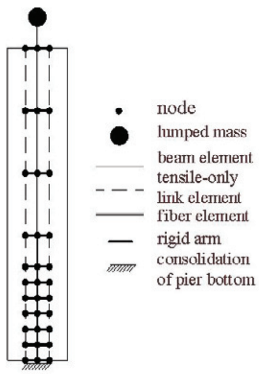
It is considered that the torsion term is elastic. After elastic torsion term is admitted onto the stiffness matrix, the element stiffness matrix without rigid modes is

$$[k] = \begin{bmatrix} [k_b]_{5\times5} & 0 \\ 0 & \dfrac{GJ}{L} \end{bmatrix} \tag{9}$$

1.3. The establishment of finite element model

Finite element model is shown in Fig.2. The pier is 10m high, including 7 reinforced concrete fiber elements (6×0.5+1)m and 3 common beam elements. It is a compression-bending member. The bending moment at pier bottom is the largest that enters plastic state first, and decreases upward gradually. So the common beam element is used which can significantly reduce calculation time by the premise of guarantee of precision.

The pier cross-section is a circle with diameter of 2m. The reinforced concrete fiber beam-column element sections is divided into stirrup constrained core concrete fiber, cover concrete fiber and reinforced fiber, referring to Fig.3. Concrete grade is C40; the longitudinal reinforcement are 61 Φ 28; section reinforcement ratio is 1.12% and there are 4 prestressed steel strands with 12 ϕ^S 15.24.



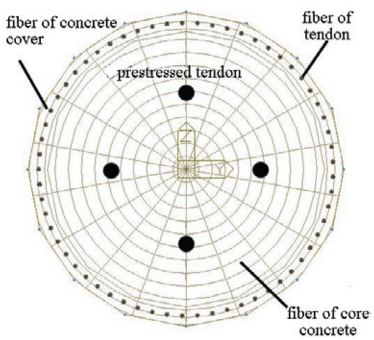


Fig.2 finite element model of the bridge pier Fig.3 the division of fiber cross-section

1.3.1. Concrete

The actual strength of concrete is improved due to the transverse stirrup and the transverse constraint effect on the core concrete from surrounding concrete. Based on previous studies, the modified Kent-Park model can well consider the constraint effect of transverse steel, especially the descending branch [9] after the maximum capacity and maximum intensity. In this paper, the constitutive relation of concrete is simulated by the modified Kent-Park model, referring to Fig.4.

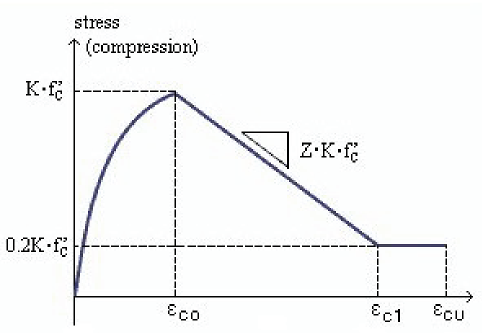


Fig.4 the modified Kent-Park model

1.3.2. Common reinforcement

Accurate simulation of hysteretic deformation characteristics of common reinforcement is important in dynamic response analysis of reinforced concrete structure. This paper adopts the Menegotto-Pinto model [10] [11], more often used in nonlinear time-history analysis of reinforced concrete structure, referring to Fig.5.

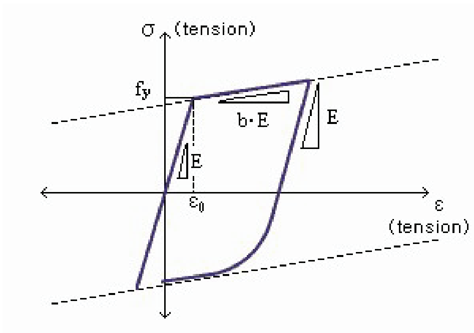


Fig.5 the Menegotto-Pinto model

1.3.3. Prestressed reinforcement

Tension bar element is used to simulate the bonded prestressed reinforcement, ignoring the possible friction between prestressed cable and cableway. The stress-strain relation model of prestressed element is ideal elastic-plastic model that it is linear elastic before condition yield. After condition yield, the yield strain and elastic modulus are appointed according to results without material hardening.

2. The finite element analysis result

With the horizonal low-period cyclic loading on pier top, as shown in Fig.6, the horizontal force-displacement hysteresis loops of bonded prestress pier can be obtained by nolinear time-history analysis, as shown in Fig.7. Then delete prestress elements, the hysteresis loops of common reinforced concrete pier is obtained, as shown in Fig.8.

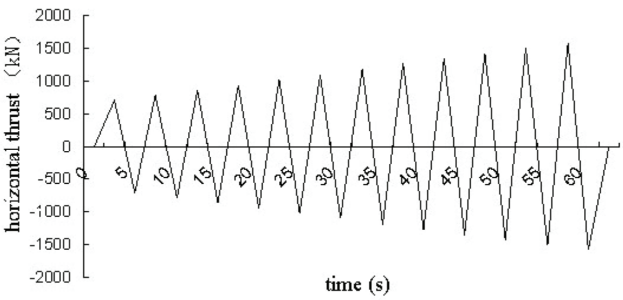


Fig.6 low-period cyclic Loading

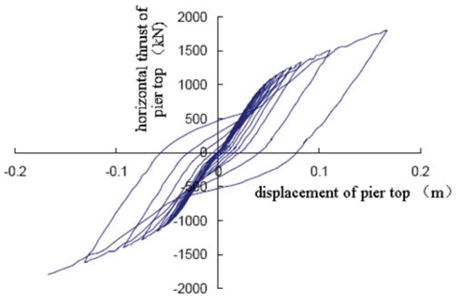


Fig.7 Hysteresis loops of the bonded prestress Reinforced Concrete Bridge Piers

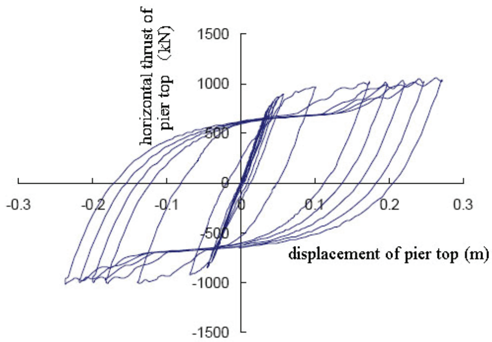


Fig.8 Hysteresis loops of the common reinforced concrete Bridge Piers

By comparing the two hysteresis loops, the hysteretic loop effect of prestressed concrete pier is obvious, and the re-centring capacity is better than that of common concrete pier. The residual deformation of prestressed pier is smaller than that of common concrete pier. But the area covered by hysteretic loop of common concrete pier is larger than that of prestressed pier, which means the former has stronger energy dissipation capacity.

3. Parameter analysis

The major factors that affect the seismic behavior of this pier include reinforcement ratio, location and tension degree of prestressed reinforcement ect. But the datum considering these factors is very rarely, thus in this paper, based on model analysis, parameter analyses of these factors are carried out.

3.1. The location of prestressed reinforcement

The distance between the location of prestressed reinforcement and section centroid is 0.4 m in the original model. Now modify the location of prestressed reinforcement respectively to the centroid, the impact referring to Fig.9. Therefore, the peak force, loading-stiffness and unloading-stiffness will increase and energy dissipation capacity decrease with the increase of the distance from prestressed reinforcement location to section centroid.

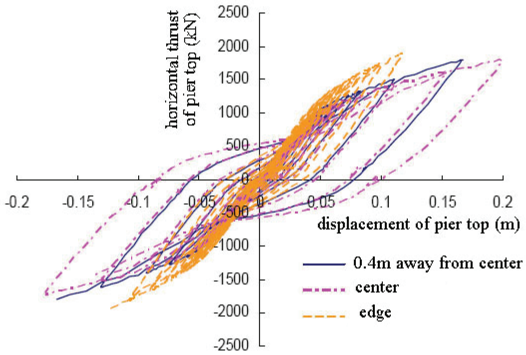


Fig.9 The impact of the location of prestressed reinforcement on hysteretic

3.2 The tention degree of prestresssed reinforcement

The tensile strength standard value of prestressed strand is 1860MPa. This paper selects three tention schemes, namely 0%, 20% and 40% of the tensile strength standard value, and the results are shown in Fig.10. Therefore, the residual deformation and energy dissipation capacity will decrease with the increase of the tention degree of prestressed reinforcement, but it has little effect on loading-stiffness and unloading-stiffness.

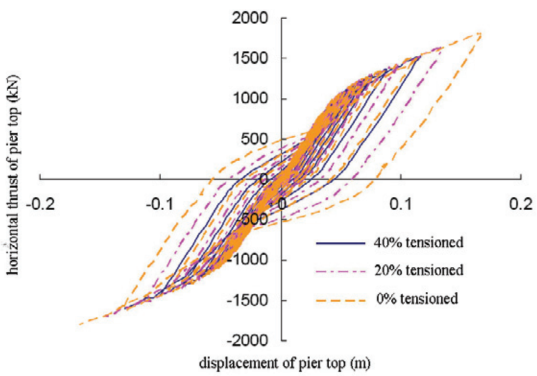


Fig.10 The impact of the tension degree of prestressed reinforcement on hysteresis loops.

3.3 The reinforcement ratio of prestressed reinforcement

The initial reinforcement ratio is 0.22%, now modify the area of reinforcement respectively to the 0.7 and 1.3 times of the initial, and the impact of the reinforcement ratio of prestressed reinforcement on hysteresis loops refer to Fig.11. Therefore, the stiffness will increase with the increase of the reinforcement ratio. However the residual deformation and energy dissipation capacity will decrease with the increase of the reinforcement ratio.

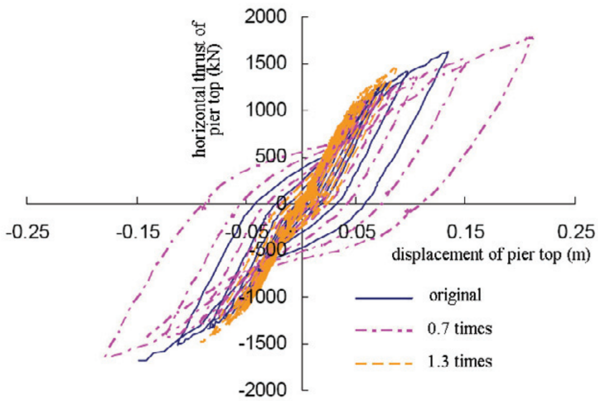


Fig.11 The impact of the reinforcement ratio of prestressed reinforcement on hysteresis loops

4.Conclusion

Fiber model analysis method based on flexibility method is carried out for integral cast in-situ prestressed bridge piers, and the nonlinear time-history analysis is conducted with the low-period cycle loading on pier top. Then the hysteresis behavior of prestressed reinforced concrete pier and common reinforced concrete pier are compared. The following conclusions are obtained.

(1)The re-centring capacity and residual deformation of prestressed reinforced pier are better than common reinforced concrete pier, but the energy dissipation capacity is worse than common reinforced concrete pier. Thus, the demands of high ductility and low residual displacement should be comprehensively considered in the design of prestressed concrete pier.

(2)The peak force, loading-stiffness and unloading-stiffness will increase and the residual deformation and energy dissipation capacity decrease with the increase of the distance from prestress location to section centroid.

(3)The residual deformation and energy dissipation capacity will decrease with the increase of the tention degree, but it has little effect on loading-stiffness and unloading-stiffness.

(4) The loading-stiffness and unloading-stiffness will increase and the residual deformation and energy dissipation capacity decrease with the increase of the reinforcement ratio.

Acknowledgements

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