Study on Seismic Mechanical Properties of Reinforced Concrete Energy Dissipation Wall and Seismic Response Analysis of Structure

Tong Zhenlong[1,2,*], Han Zhongya[1,2], Wu Zenglin[1,2]
and Yang Dongyu[1,2]

[1]*School of Civil Engineering, Zhengzhou College of Finance and Economics, Zhengzhou Henan 450044, China*
[2]*Zhengzhou Engineering Research Center of Construction Asset Management Information, Zhengzhou Henan 450000, China*
E-mail: tongzhenlong@zzife.edu.cn
[*]*Corresponding Author*

Received 26 January 2024; Accepted 13 March 2024;
Publication 29 March 2024

Abstract

Utilizing the nonlinear finite element analysis software, ABAQUS, an examination is undertaken to evaluate the ductility characteristics and seismic design methodologies pertinent to a representative reinforced concrete hollow high pier. The research encompasses several focal areas: elucidation of seismic design strategies related to ductility categories, exploration of plastic energy dissipation mechanisms, determination of ductility indices, and delineation of structural measures to enhance ductility. Employing the nonlinear FEA software, ABAQUS, it is recommended that the longitudinal reinforcement ratio for ductile piers fall within the range of 0.6% to 4%. Furthermore, for flexible bridge piers, the maximum spacing of confinement

European Journal of Computational Mechanics, Vol. 33_1, 71–90.
doi: 10.13052/ejcm2642-2085.3314

reinforcements should either exceed 100 mm, be sixfold the diameter of the longitudinal reinforcement, or equate to at least one-quarter of the pier column's bending direction section width. Combined with the influence of high pier ductility seismic axial pressure ratio, reinforcement, concrete factors such as factor analysis results, put forward and checking a reinforced concrete hollow high pier ductility seismic optimization scheme, increase the strength of the plastic hinge area section, through the comparative analysis in different seismic strength of plastic hinge unit cloth, maximum ductility coefficient and pier top displacement to verify its influence on the ductile seismic.

Keywords: Hollow bridge pier, plastic hinge, ductility performance, seismic design method, finite element analysis and curve Fertility factor.

1 Introduction

The advancement of civil engineering within a nation correlate directly with the growth trajectory of its national economy and holds significant implications for both its current status and prospective development. Therefore, as an important member of the civil engineering family, the development of bridge is more worthy of attention [1, 2]. Data show that in China's highway construction, 2006-2010 "11th Five-Year" period, the newly built highway in the west of more than 40 0,000 kilometres, equivalent to 11 times around the earth [3, 4]. In the aspect of railway construction, the total railway investment in western China accounts for more than half of the total railway investment in the same period. Due to the complex western landscape type, mountain area is large, so the western highway railway line inevitable to cross deep gully [5, 6], so the bridge often accounts for a large proportion in the line, mountain bridge using high pier can make bridge type more reasonable, economic, cost saving, in recent years some our country built or high pier bridge under construction. With the implementation of the strategy of the western development policy, so the high pier bridge to face the seismic problem is more prominent [7, 8].

Otherwise it will cause the damage of the bridge support, serious will cause the earthquake damage of the falling beam. In the seismic design of the high pier [9, 10], if the section of the pier column increases, it will be accompanied by the increase of the seismic force. In this way, the contribution of the cross section to the seismic effect will be reduced, and when the pier height reaches a certain limit, the increase of the cross section will adversely affect the earthquake resistance of the pier column. At the same time, the gap of high pier in mountainous areas is relatively large and is very irregular in structure, so the analysis of seismic response is relatively complex. Bridge is the top priority of lifeline engineering, which plays a key role in earthquake relief, emergency rescue and bridge reconstruction after the earthquake [11, 12]. Therefore, the bridge should have its most basic application ability after experiencing earthquake damage. The seismic design of high pier Bridges is not clearly stipulated in the seismic design codes of various countries, so the existing seismic codes of Bridges at home and abroad are not applicable to high pier Bridges [13, 14]. At the same time, the traditional bridge seismic mode lacks the self-regulation ability for the structure, and the requirement for safety is very difficult to achieve under the uncertain ground vibration. Therefore, it is very necessary to study a new seismic design concept of high pier bridge [15, 16].

2 Seismic Design Method of Reinforced Concrete High Pier Ductility

2.1 Productive Seismic Design

The ductility capacity of the pier and pier section size, longitudinal reinforcement, transverse reinforcement, concrete grade and axial pressure ratio, etc., the Equations (1) and (2) expressed the above relationship, in order to obtain the best high pier ductility seismic performance and economic benefits, for the study of these factors to obtain a reasonable high pier ductility design is crucial.

$$\alpha x = \frac{\beta t}{\beta x}(t = x) \tag{1}$$

$$\partial_{\Delta} = \frac{\Delta x}{\Delta t}(x \neq t) \tag{2}$$

At present, the mainstream idea of bridge seismic design code is ductile seismic design. Its main design contents mainly include: conceptual design of bridge ductility, secondary design of ductile bridge components, seismic structure design and capability protection design. Equations (3) and (4) express the above design content. The design method of ductile bridge mainly includes three contents: structure system, plastic energy consumption mechanism and the selection of ductility type.

$$\delta_x = 1 + \frac{y_d - 1}{3\lambda(1 - 0.5\gamma)} \tag{3}$$

$$\lambda = \frac{Lh}{L}(h = 1, \ldots, 52) \tag{4}$$

For a bridge, a reasonable structural seismic system can be very effective to reduce the seismic damage of the bridge. Bridges with different importance can choose different ductility design types. Equations (5) and (6) indicate the above design types, so as to obtain the best ductility seismic goals and economic benefits.

$$\Delta\sigma = \Delta y + (\chi v - \chi z) \times Lp \times \left(h - \frac{L}{2}\right) \tag{5}$$

$$\mu = \frac{1}{2} \times \left[\left(\frac{K_{ht}W}{P_c}\right)^2 + 1\right] \tag{6}$$

The choice of plastic energy consumption mechanism is mainly the choice of the expected plastic hinge position. Equation (7) indicates the expected plastic hinge position, which should follow the principle of energy conservation, so as to obtain the optimal energy consumption mechanism.

$$\sigma_s = \frac{4 \times A_d}{D_s S} \tag{7}$$

Dtility bridge components of the secondary design this method is following the general seismic design of small earthquake to ensure the structure ductility ability again, Equation (8) said the ductility ability, its main design purpose is to ensure that the structure under the action of strong earthquake can enter the ductility energy phase, and at the same time can have the design expected ductility level, meet the design expected ductility seismic requirements.

$$\rho_w = \frac{A_{sw}}{S_l \times_B} \tag{8}$$

Equation (9) represents the ductile components, its main design idea is to set the appropriate strength grade difference between, make seismic delay component before the ability to protect components into the delay stage, so that the ability to protect components from brittle failure.

$$W_{wd,r} \geq max\left(w_{w,red}, \frac{2}{3}W_{w,min}\right) \tag{9}$$

Structural design mainly includes the configuration of transverse reinforcement, longitudinal reinforcement and the determination of reinforcement rate, steel lap and anchorage method and the length of the plastic hinge area value, the Equation (10) said the value range, and a series of anti-fall beam measures, structural measures of a bridge seismic performance for seismic structure design is also very important.

$$\chi_{\chi} = \frac{N_{ed}}{A_{CF}C_K} > 0.078 \tag{10}$$

2.2 Ductility Index of Reinforced Concrete High Pier

According to the functional requirements and deformation behavior of the bridge, the design ductility of the bridge structure can be divided into: limited, limited and complete ductility. Complete ductility means that the structure can form a plastic hinge in some specific parts under the expected small probability earthquake, so that the ductility performance of the structure can be fully played, and other parts except these specific plastic hinge areas do not occur inelastic deformation. Equation (11) expressed the maximum ductility, limited ductility refers to the structure under the action of earthquake in some not easy to find and not easy to detect is likely to form plastic hinge, in the overall deformation of the structure, part of the component into the nonlinear deformation stages its deformation is larger, and part of the component is still in the elastic deformation stage its deformation is relatively small, the structure on the whole is part of the ductility.

$$Wwd, c \geq max(1.4 \times w_{w,req}, W_{w,min}) \tag{11}$$

Restricted ductility refers to the limitation of the structure due to the structural measures, functional requirements and the interaction of different loads. Equation (12) represents the minimum value of the limit. Compared with the limited and limited ductility, the structural ductility ability of the full ductility has been fully played. It has stronger energy consumption performance, and at the same time, its design seismic force can be greatly reduced, and its economic benefits are very good.

$$W_{min} = [0.1\eta_k + 4.17 \times (\eta_k - 0.01) + 0.02]\frac{f_c}{f_{yh}} \geq 0.004 \tag{12}$$

But on the other hand, finite and limited ductility have better seismic performance. For the general middle and low pier bridge usually adopt the complete ductile structure design, which is more economical. For important Bridges, it is usually not suitable to adopt the complete ductility structure form, but from the seismic performance consideration, usually choose the limited ductility or limited ductility structure form [17, 18]. The plastic hinge of ordinary bridge usually appears at the bottom of the pier. In order to obtain the best economic benefit, the complete ducdesign is usually adopted. Different from the general ordinary bridge, the plastic hinge of the high pier bridge is affected by the high order vibration type, and the plastic hinge may appear in the pier bottom and pier, and more than one appears [19].

In the middle and low piers of the bridge, the overall ductility ability of the bridge is reflected by the displacement ductility coefficient of the pier top, while the local ductility ability of the bridge is reflected by the corner of the plastic hinge area [20]. Under the action of seismic load, the plastic angle and displacement ductility of middle and low pier are not affected, so the displacement extension coefficient and plastic angle of medium and low pier can be calculated by static method [21, 22]. However, due to the influence of high order vibration type, the displacement ducability and plastic corner of the high pier may be affected by the seismic load and the mass of the pier, and the maximum displacement of the high pier and the maximum section curvature of the pier bottom are not synchronized [23]. Figure 1 shows the analysis and evaluation of ductility capacity. It may be unreasonable to take the pier top displacement as the calculation standard, so it is necessary to reasonably select the performance index of high pier ductility performance. The reinforced concrete high pier bridge adopts the limited ductility as the ductility category.

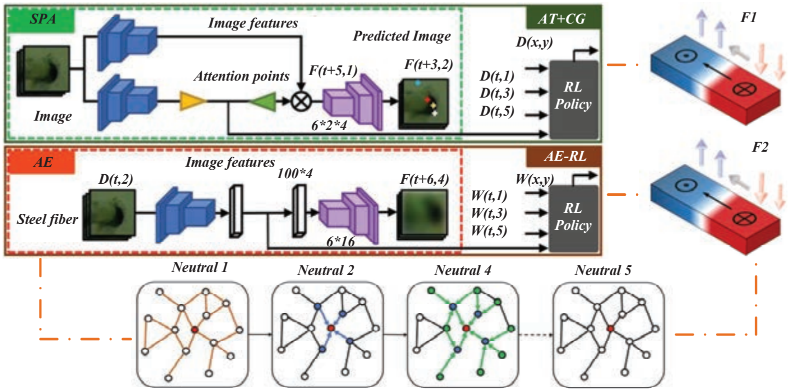

Figure 1 Analysis and assessment of ductility ability.

3 Nonlinear Simulation of Reinforced Concrete

3.1 Easicoplastic Fiber Beam-Column Unit

Because the high pier bridge is in general not irreplaceable in the road line. When the high pier bridge encountered the earthquake caused serious damage or even damage, it will cause very serious economic losses, and even cause social unrest. In general, the high pier bridge according to the full elastic design is not appropriate, but also uneconomic behavior, and it is not feasible for seismic requirements [24]. Therefore, the ductile seismic design target of reinforced concrete high pier bridge should be small shock and can be repaired after large earthquake. Related studies show that “under the action of relevant ground motion. Therefore, the plastic energy consumption mechanism of the high pier bridge is the expected plastic hinge position. It is generally recommended to be set at the bottom of the pier to dissipate the seismic energy [25, 26], through the stagnation characteristics of the plastic hinge area at the bottom of the pier. In the modern reinforced concrete bridge structure, the destruction of concrete piers leads to the destruction and even collapse of the bridge has become one of the most important features of the bridge damage, so how to correct and reasonable the nonlinear characteristics of the reaction structure has always been the focus of scholars at home and abroad [27]. Scholars at home and abroad have adopted many types of units to simulate the nonlinearity of the structure, but only the elastic-plastic fiber beam and column units and the elastic-plastic beam and column units are widely recognized. However, the elastic-plastic beam and column unit will have a certain length limit on the inelastic deformation area of the reinforced concrete parts, and the length of the plastic area changes with the change of loading history, which makes the calculation results inaccurate to a certain extent. Therefore, it is recommended to use the elastic-plastic fiber beam-column unit to simulate the nonlinear of the reinforced concrete structure. Figure 2 shows plastic rotational ability analysis, elastoplastic fiber model is the reinforced concrete beam and column unit section divided into a certain number of discrete forms of fiber unit, any one of the fiber units can be reinforced material or concrete material, the mechanical characteristics of each fiber unit with the above concrete, reinforcement stress-strain relationship. Such a fiber model can accurately reflect the material performance and reinforcement distribution of reinforced concrete parts, and can consider the influence of axial force, unidirectional and bidirectional bending moment on the force relationship of section recovery [28].

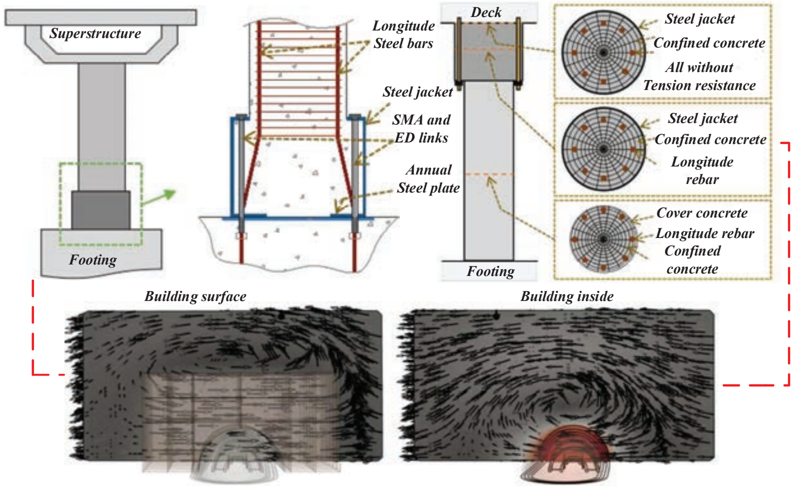

Figure 2 Analysis of plastic rotational capacity.

For the general reinforced concrete members, the bending usually occurs when the force. Under normal circumstances, the force of the member changes along the direction of the rod shaft, and the cracking of the reinforced concrete beam and column member increases with the load in the process of deformation, which leads to the continuous degradation of the section stiffness. For the deformed reinforced concrete members, the bending moment-curvature recovery model of the members should be established at the section level of the members. Integrating the flexural stiffness of the section along the length of the member can obtain the hysteresis characteristics of the corresponding member and the change of the bending stiffness of the beam-column member along the axial section. The plastic Fiber unit has two main advantages: it is a unit formed based on the flexibility method, so it will not produce the discrete error caused by the distribution of the plastic unit based on the stiffness method; second, the nonlinear performance of the elastic-plastic Fiber unit material is good, which is very suitable for simulating the elastic-plastic deformation of the member. By selecting different Fiber material models, it can more truly reflect the properties of concrete and reinforcement, and at the same time can reflect the core concrete inside the stirrup and the stress performance of unconstrained concrete outside. At the same time, by studying and analyzing the stress-strain relationship of the corresponding key points, we can further grasp and understand the nonlinear reaction law of the components [29].

3.2 Basic Theory of the Nonlinear Finite Elements

The nonlinear problem of a structure can be understood as an analytical problem where the stiffness of a structure changes with its deformation. In reality, the structural force deformation is not linear, and the usual linear analysis is not absolutely accurate, it is an assumption made to facilitate the calculation, which is generally accurate enough for the design. In the theory of plastic mechanics for the structural materials. There are three important basic criteria: yield, flow and reinforcement criteria. The flow criterion reflects the direction of the material plastic strain when the material yields, that is, the plastic strain increment changes with the stress increment. Three reinforcement criteria are provided in ABAQUS, in which the isotropic reinforcement criterion is more applicable to the large strain problem, while the random reinforcement criterion applies to the small strain problem, and the other mixed reinforcement criterion is not common in practical applications [30]. In ABAQUS software provides a variety of plastic material options, which is the following four: bilinear to strengthening BISO, bilinear reinforcement BKIN, multilinear to strengthening MISO and multilinear MKIN geometric nonlinear refers to the structure after the load deformation is larger, is relative to the structure before the large angular displacement or linear displacement, resulting in geometric nonlinear phenomenon, including large displacement, large strain and stress stiffness. Large strain also includes three factors that cause the change of structural stiffness, including cell direction change, cell shape changes and stress stiffness effect. Large displacement includes the "large rotation" and stress stiffness effect, but it is still assumed to be "small strain". In this paper, when studying the ductility of the structure, a large displacement must be applied on the top of the pier, which makes the analysis problem geometric nonlinear.

Material nonlinearity refers to the structural nonlinearity caused by the nonlinear stress-strain relationship of the material itself, which can be divided into two categories: time-dependent viscoelastic and viscoplastic problems and elastic-plastic problems independent of time. In this paper, the pier plastic hinge will enter the plastic strengthening stage with the increase of loading, and its deformation and strain are large, so there is the problem of material nonlinearity. The finite element analysis software ABAQUS has its rich unit library, divided into eight categories: shell unit, solid unit, thin film unit, rod unit, beam unit, rigid body unit, infinite element and connection unit. Figure 3 shows the simulated seismic force model. This paper studies the ductility performance of bridge high piers under the action of simulated seismic

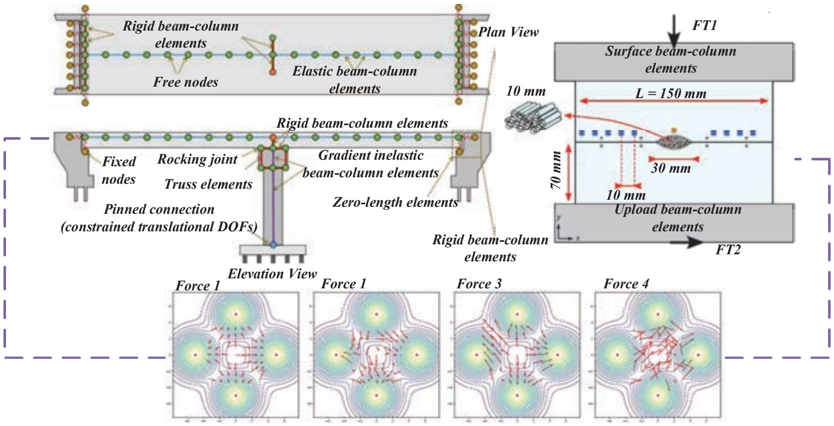

Figure 3 Simulated seismic force model diagram.

force, and should be applied to the continuum unit of stress-displacement. In ABAQUS, the types of continuum units are very rich, including three-dimensional and two-dimensional secondary units and linear units, which can use complete integral and subtraction integral respectively, in addition, there are modified Tet and Tri units, and hybrid mode units and non-coordinated units.

The model of the bending reinforcement only considers the compression bending of the reinforcement. The tile seismic capacity of bridge high pier, the structure should be loaded until the elastoplastic deformation stage and the failure limit state. The injury plasticity model proposed by Lee and Fenves to determine, it is designed to analyse that, under the conditions of cyclic loading and dynamic loading, For the mechanical response of concrete structures to provide appropriate material models, It takes into account the tensile properties of the material, It is mainly used to simulate the non-recoverable material degradation due to damage under low hydrostatic pressure. The plastic injury model is a continuum injury model based on the plasticity theory. The model can be used for one-way loading, dynamic loading and cyclic loading, while the model has good convergence.

4 Analysis of Seismic Response of Reinforced Concrete

The concept of “ductility” was first put forward in the 1960s. Later, in the earthquake, some Bridges were damaged in the design, and collapsed in serious cases. Scholars at home and abroad gradually realized the importance

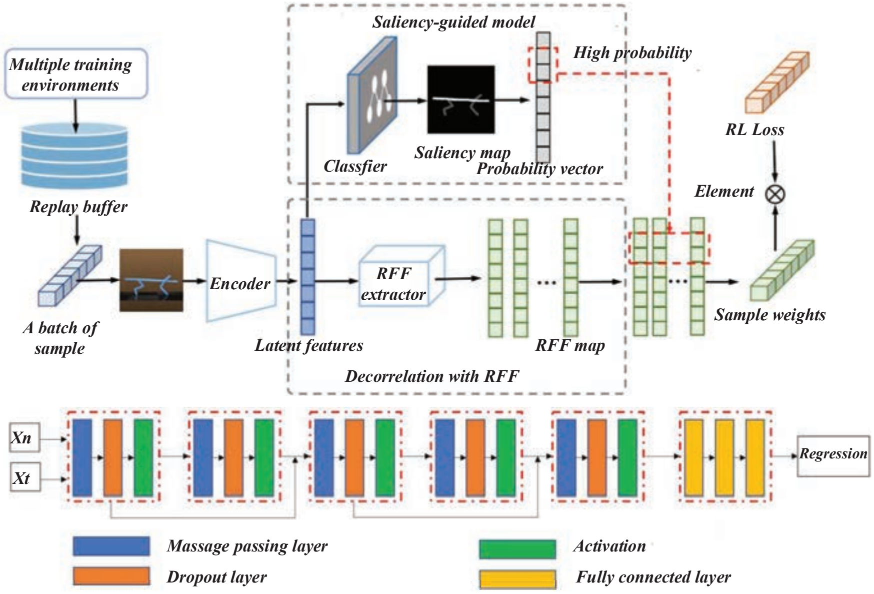

Figure 4 Higher-order pattern analysis diagram.

of ductility design. Then in the 1970s, a group of New Zealand scholars first proposed a method of structural ductility ability design, which is the first time of the ductility seismic design method theory. Ductility seismic the main idea is: the structure under the action of strong earthquake through the use of local inelastic deformation to dissipate and absorb seismic energy, and while the structure on the whole keeps appropriate strength, usually in the ductility seismic design, using the pier under the preset plastic hinge area of nonlinear deformation to dissipate the earthquake energy on the structure.

In the seismic design of bridge, it is necessary to calculate the reaction of bridge structure under earthquake action. Figure 4 shows the analysis diagram of high-order vibration type, which is an important factor affecting the response of high-pier bridge under earthquake action. General middle and low pier bridge structures can rely on their own strength to resist earthquake action when encountering small and medium earthquakes. However, considering the intermittence and uncertainty of large earthquakes and extremely rare earthquakes, the elastic design alone is not economic and not feasible for the high pier bridge. There is no clear specification for the seismic design of high pier bridge, which is a drawback in the current seismic design of highway bridge in China. The ductility performance of reinforced concrete piers can be determined by analysing the curvature moment of the plastic hinge area. In the above formula, the internal force-resultant force of reinforcement is expressed by the summation term, while the internal force of concrete is expressed by the integral term. In the calculation, the unconstrained concrete is selected for the type of peripheral protective layer concrete, and the concrete in the core compression area with stirrup restraint should choose the constrained concrete, so the choice of stress-strain relationship between these two kinds of concretes is different. In the relationship of reinforcement stress-strain and the protective layer unconstrained concrete and core constrained concrete are known, we can use the computer program to calculate the above two types, so as to get the section moment-curvature curve of the component. Strain increment method or curvature increment method is usually used to calculate the moment-curvature curve of the section. For the value of the moment calculated in response to a series of curvature values, the calculation process needs repeated iteration until the specified limit curvature is reached. The expressed axial force balance conditions can be satisfied.

The reaction of the structure under the earthquake mainly depends on two aspects: one is the influence of the ground motion characteristics, the amplitude and period; the other is the structure itself, its section form. The increasing rate of the yield moment begins to increase, And the coaxial pressure ratio is a linear relationship; The trend of the limit bending moment with the axial pressure ratio is similar to the yield curvature. The rate of decrease of the curvature ductility coefficient also gradually slows down. It is deduced that the ductility coefficient associated with the maximum curvature of the reinforced concrete hollow high pier diminishes as the axial pressure ratio escalates, signifying a detrimental influence. However, upon surpassing a specific threshold value of the axial pressure ratio, further increments in this ratio progressively compromise the pier's ductility.

5 Experimental Analysis

In the context of typical middle and low pier bridges, under seismic conditions, the plastic deformation typically manifests at the pier's base. However, when considering the prospective plastic hinge regions of elevated pier bridges under seismic influences, this conventional observation may not uniformly hold true. The distribution of plastic hinge area of high pier bridge is affected by high order vibration type. Enter different seismic waves and gradually enlarge the horizontal seismic acceleration A (peak of 0.15 g)

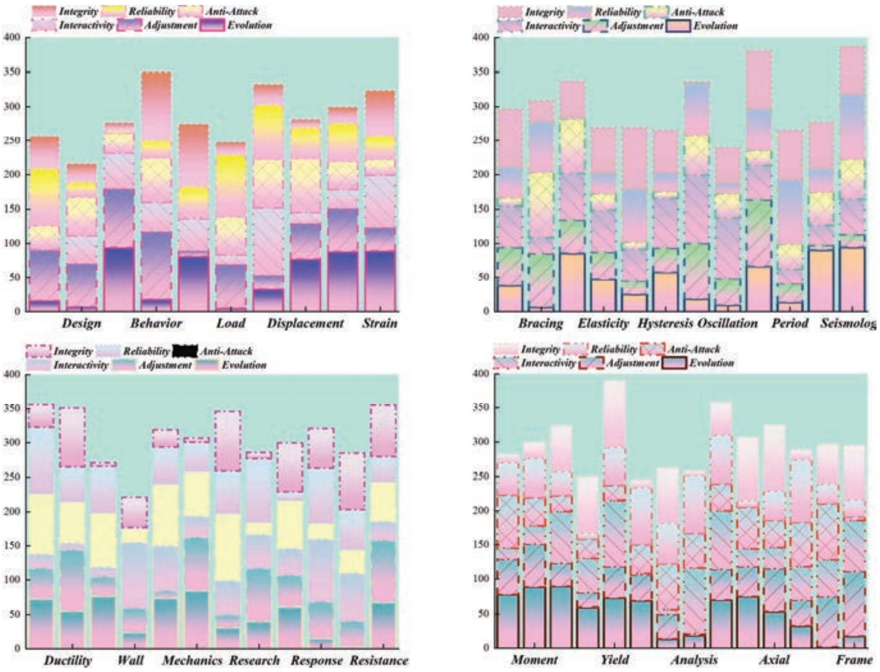

Figure 5 Seismic wave assessment.

to 4A. Figure 5 shows the seismic wave assessment diagram to analyse the formation and development of the pier plastic hinge under the simulated seismic wave.

The manifestation of its stochastic nature is pronounced, manifesting not merely at the base of the pier but potentially extending throughout the structure. In scenarios where the plastic hinge emerges simultaneously at both the pier base and its upper section, Figure 6 delineates the demarcation of the plastic hinge zone. Relative to situations where the plastic hinge is solely evident at the pier's base, an observable escalation in displacement occurs at the pier's apex, thereby compromising the seismic resilience of the elevated pier bridge. When the displacement is too large, it will cause collision or even falling beam harm. By establishing the strength grade difference between the plastic hinge area of the high pier and the section outside the plastic hinge area, the plastic hinge area can appear in the preset place, so as to improve the ducability of the pier column.

The pier column from the bottom of the pier top evenly divided into 20 section, each corresponding to a section number, 1 section for pier cap,

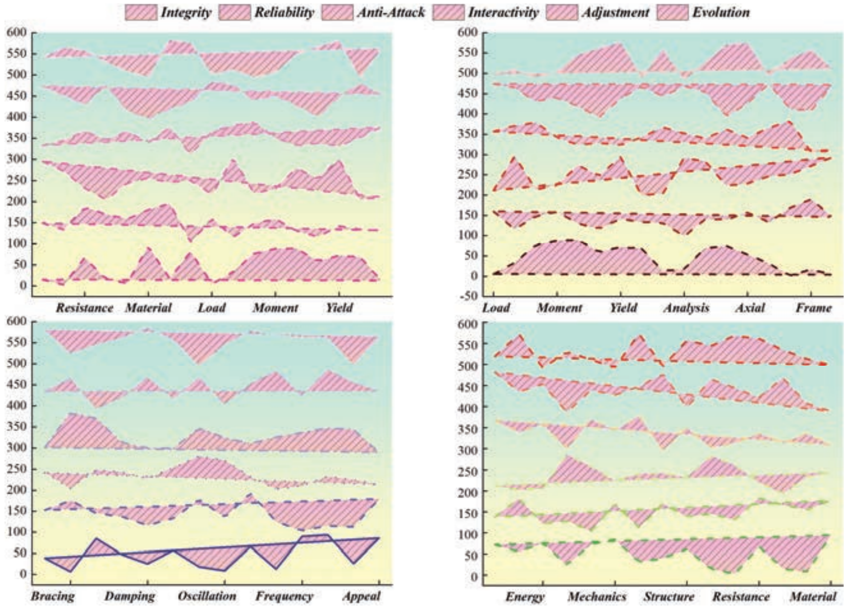

Figure 6 Identification map of plastic hinge area.

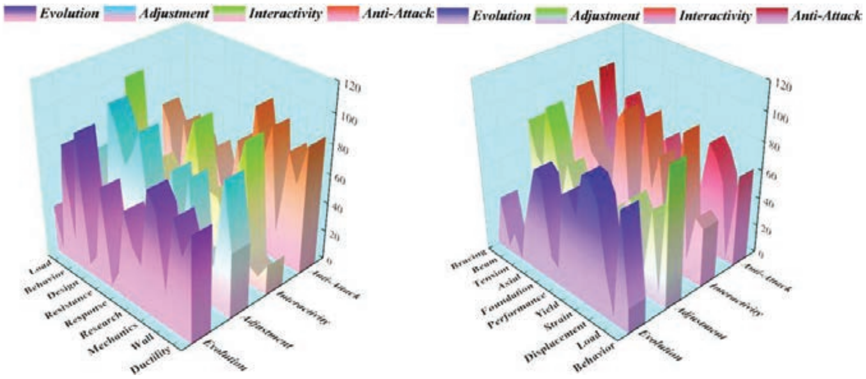

Figure 7 Section strength diagram

plastic hinge area set in the unit corresponding to the Sections 3 and 4, Figure 7 section strength, increase plastic hinge area section longitudinal reinforcement, respectively increased to the original reinforcement rate of 1.5 times and 2 times, improve the strength of the plastic hinge area section, study and analyze the seismic response of bridge pier in several cases.

6 Conclusion

In this study, the nonlinear finite element analysis software ABAQUS was used to test the ductility characteristics and seismic design methods of representative reinforced concrete hollow high piers. The main research results are as follows: The increase in axial compression ratio has an adverse effect on the ductility of typical hollow reinforced concrete high piers. Used for the ductility of bridge piers when not exceeding a certain value. However, as the reinforcement ratio continues to increase, the ductility of the pier column will actually decrease. Increasing hoop ratio of reinforced concrete hollow high piers can improve ductility performance. The increase in longitudinal steel bar strength has a dual adverse effect on the ductility characteristics of reinforced concrete hollow high piers. The effect of increasing the strength grade of concrete on the elongation performance of reinforced concrete hollow bridge piers is negligible. Excessive increase in concrete strength can have contradictory adverse effects, therefore the longitudinal reinforcement ratio of ductile piers should not be less than 0.5% and should not exceed 4%. For areas with seismic fortification intensity of 8 degrees or below, the spacing between hoop bars in the lap joint of restrained steel bars for ductile piers should not exceed 100 mm. In areas with seismic fortification intensity greater than 8 degrees, the spacing between hoop bars should not exceed 5 cm.

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Biographies

Tong Zhenlong received the bachelor's degree in engineering from Zhengzhou University in 2009, the master's degree in engineering from Henan University of Science and Technology in 2019. He is currently working as an Associate Professor at the School of Civil Engineering Zhengzhou College of Finance and Economics. His research areas and directions include mechanics, BIM technology, carbon emissions.

Han Zhongya received the bachelor's degree in engineering from Henan University of Economics and Law in 2016, the master's degree in engineering from Zhengzhou University in 2019. She is currently working as a lecturer at the School of Civil Engineering Zhengzhou College of Finance and Economics. Her research areas and directions include mechanics, BIM technology, intelligent construction.

Wu Zenglin received the bachelor's degree in engineering from Xinyang Normal University in 2014, the master's degree in engineering from China Three Gorges University in 2017. She is currently working as a lecturer at the School of Civil Engineering Zhengzhou College of Finance and Economics. Her research areas and directions include mechanics, BIM technology, reinforcement and treatment of ground.

Yang Dongyu received the bachelor's degree in engineering from Pingdingshan Institute of Technology in 2008, the master's degree in engineering from Qingdao University of Technology in 2010. He is currently working as an Associate Professor at the School of Civil Engineering Zhengzhou College of Finance and Economics. His research areas and directions include urban informatization modeling, optimization of water supply and drainage network.