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Bridge Seismic Shear Capacity in the Design of Experimental Research

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Abstract: Deeply at home and abroad are introduced in the seismic design of shear capacity of research, put forward different shear strength calculation formula of plastic hinge area. The failure mode of plastic hinge area piers shear strength study has certain reference significance.

Keywords: Seismic design; Plastic hinge; Shear strength

1. Introduction

Our country's B02-2008 JTG/T "highway bridge seismic design rules" (hereinafter referred to as the rules) used the ductility seismic design theory. According to this theory, the reinforced concrete pier is a ductile member, which can be used to dissipate seismic energy by plastic deformation of plastic hinge in a specific area .In order to give full play to the deformation and the capacity of energy dissipation of plastic hinge , and to make the bridge pier occurrence of ductile bending failure mode expected under the strong earthquake .The brittle shear failure of ductile member in plastic hinge region must be prevented .Therefore, it is an important part of the bridge structure ductility seismic design how to ensureensure the shear bearing capacity of the plastic hinge area of the ductility artifacts .

2. The General Situation of the Research on the Shear Resistance in the Design of Foreign Countries

2.1. Japan

The seismic performance of reinforced concrete frame columns was studied by the Japanese construction center from 1976 to 1972 .In order to study the shear strength of reinforced concrete columns under seismic load, the experimental personnel made a model of twelve reinforced concrete columns .The main parameters are: the axial compression ratio of 0~0.5, the change range of the lateral stirrup ratio is 0.33%~1.47% .and the total deformation value of each cycle (displacement and reinforced strain) would be detected.

Through the pseudo static loading test, the following conclusions are drawn:

when the concrete began to appear crack distresses in compressive region, the shear mechanism for the corresponding deformation of the reinforced concrete member is changed obviously. Main change symbol is that the shear is shifted from compression zone to concrete reinforcement.

when not enough transverse stirrup configuration to constrain the core concrete and bear all shear ,the reinforced concrete members into non elastic deformation under cyclic loading, the strength and stiffness are significantly reduced.

The strength and stiffness of the member is attenuated due to the axial force under cyclic loading.

2.2. The United States

A concept model of the anti shear strength is presented in the "seismic design" (1981) (ATC-6) on the ATC (the Applied Technology Council). According to this model, the ductile bending failure can be ensured when the shear strength of the flexural strength of the reinforced concrete bridge pier is smaller than that of the plastic hinge region .The brittle shear failure occurs when the shear strength is greater than the initial shear strength. When the flexural strength of the corresponding shear strength is between the initial shear strength and the shear strength of the plastic hinge region. The strength and load deformation relationship curves are corresponding to a certain ductile shear failure , that is, bending shear failure.

Based on the "ATC-6" model, Ang et through the experimental study, the calculation formula of shear strength considering the influence of bending ductility is presented. The experimental results show that the initial shear strength increases with the decrease of the shear span ratio and with the rise of axial compression ratio. Then the experimental data are grouped according to the different shear span ratio. the experimental data can be found to have a significant effect on the components, and the influence of shear span ratio is no more than 2.It is also found that the influence of axial load on the shear strength is obviously lower than that of the initial shear strength, and the shear strength of concrete is affected by the concrete in the core area of the transverse reinforcement .In the initial stage of elasticity and low ductility stage. Oblique cracks and pier axial column angle θ is 45 degrees, θ decreases with the non elastic deformation increases, According to the test results , the formula for shear strength calculation of initial shear strength and plastic hinge region is presented by Ang :

$$V_i = V_{ci} + V_{si} = 0.37(1+\frac{3P}{f_c' A_g})\sqrt{f_c'}A_e + \frac{\pi A_{sv} f_{yv} D'}{2S} \quad (1)$$

D':Column section effective height;
P:Design axis pressure;
fc':Axial compressive strength of concrete cylinder;
Ag:Cross section area
Ae:Effective area;
Asv:Transverse section area
fyv:Yield strength
S:Transverse bar spacing.

$$V_i = V_{ci} + V_{si} = 0.185\beta\sqrt{f_c'}A_e + \frac{\pi A_{sv} f_{yv} D'}{2S}\cot\theta \quad (2)$$

β=100βsv≤1, βsv =4Asv/(D'S):Lateral coupling ratio, cotθ=[(1-ψ)/ ψ]1/2,
ψ=βsv fyv/(0.2 fc').

According to the relationship between the displacement ductility factor and the failure form, the failure mode of the specimen is divided into three categories by Ang et al.:

Bending ductile failure: when the ductility level reaches μΔ≥6, without any shear failure phenomenon.

Bending shear failure :when the ductility level is 2< μΔ <4, the bending shear failure occurs.

(3) brittle shear failure: μ Δ≤2, the member has a shear failure. These components can't bear the shear force corresponding to the bending strength.

Through to a lot of reinforced concrete bridge pier model of cyclic loading tests on, Priestly et al pointed out: the shear strength of plastic hinge region decreases with the increase of ductility ratio, which is mainly due to incurved shear crack width of plastic area increases on, Under the action of bending ductility, the aggregate interlock transmission reduce the shear. The experimental results show that the angle between the inclined crack and the column axis decreases with the increase of ductility, which reflects the improvement of the shear capacity of the truss mechanism.

3. General Situation of Shear Resistance in the Domestic Seismic Design

3.1. China

In 1989, the research group in China carried out 86 square and rectangular cross section frame columns with low cycle repeated load test. The coupling ratio was 0~1.47%, the longitudinal reinforcement ratio was 0.61~2.5% , Shear span ratio of 1~ 3, and the axial compression ratio was 0~1.62.

In the research report, the strength of the anti-shear weaken of the frame columns under cyclic loading is caused by low cycle fatigue. The rate of diagonal tension failure and shear failure is the fastest under large deformation, bond failure second and the shear failure is slow.

Figure 1. The vibration of the Bridge Pier

Cross diagonal crack damaged the shear resistance of the whole concrete cross section, and changed the shear resistance mechanism of the column, so that the shear resistance of concrete decreased gradually. Changing the coupling ratio and the form of the hoop can improve the shear strength of the columns in the large deformation. At the same time, the shear strength formula of the frame columns under low cyclic reversed loading is presented:

$$V_u = \frac{0.1}{\lambda+0.1} f_c b h_0 + 0.8\frac{f_{yv}A_{sv}}{S}h_0 + 0.07P \quad (3)$$

Guan Pinwu et al. Through the analysis of shear capacity of reinforced concrete frame columns under cyclic loading, the shear mechanism of concrete frame columns under earthquake action is different from that of static load.

Due to the effect of repeated load, the cross crack of the component is generated, which destroy the shear resistance of the whole concrete section, reduce the shear area of concrete and the shear resistance of concrete is weakened.In the whole process, The shear contribution of concrete decreases gradually , the stirrup contribution increases gradually.

At the same time, it is pointed out that the degradation of the shear strength of the component is increased with the increase of the ductility factor, which is related to the non elastic deformation and cyclic loading times. So the concrete contribution should be evaluated according to the structural deformation, that is evaluated according to different levels of structure seismic, the shear bearing capacity of the frame column is presented.

$$V_u = \frac{1}{r_{RE}}(\frac{\alpha_c}{\lambda+1} f_t b h_0 + \frac{f_{yv}A_{sv}}{S}h_0 + \alpha_N N) \quad (4)$$

αc,: Shear contribution of concrete
αN: Seismic influence coefficient of axial force
N: Design of frame column axial force considering the combination of seismic action

Wang Huijia made 10 140mm x 140mm reinforced concrete short column model, the ratio of longitudinal reinforcement is 1.6%, the ratio of the coupling is 0.34, the maximum is 0.81%, the compressive strength of concrete is 10.2MPa~29.5MPa.

Based on the experimental study ,the shear failure process and the characteristics of a small shear span ratio of the reinforced concrete frame columns, the failure mechanism of a small shear span ratio of the reinforced concrete member is discussed. He draws the following views:

the failure mode of the small shear span ratio component with the axial compression ratio of N can be divided into two types: the shear diagonal tension failure of small axial compression ratio, the shear failure of large axial compression ratio.

The relationship between shear strength and axial compression ratio is nonlinear, with the increase of axial compression ratio, the shear strength increases first and then decreases.

Member of small shear span ratio shall be appropriate to consider the beneficial effect of the longitudinal reinforcement.

the ductility of small shear span ratio is very small, so that it can meet the requirements of ductility, and should be constructed from the structural aspect, and try to convert the shear failure mode to bending failure mode.

According to the test results, shear strength calculation formula of reinforced concrete short columns subjected to low cyclic bending moment and shear force at the same time is presented:

$$V_u = \frac{0.1}{\lambda+0.3} f_c b h_0 + \frac{1.3}{\lambda}\frac{f_{yv}A_{sv}}{S} h_0 + 0.12P \quad {}_{0\le n\le 0.5} \qquad (5)$$

$$V_u = \frac{0.1}{\lambda+0.3} f_c b h_0 + \frac{1.3}{\lambda}\frac{f_{yv}A_{sv}}{S} h_0 + 0.1(1-0.8n) f_c b h_0 \quad (0.5\le n\le 1) \qquad (6)$$

Liu Boquan et studied the low cycle fatigue properties of 8 materials with different axial compression ratios (0.20and 0.353) under cyclic loading with equal amplitude, and explored the development law of accumulative damage under different displacement amplitude.

They think that the damage of Ductile Reinforced Concrete Structures under earthquake action can be seen as the result of the accumulated damage caused by the magnitude of the displacement amplitude, and the displacement value of each over yield will increase damage control site, when the damage accumulates to a certain extent, the site will be destroyed or crushed.

3.2. Plastic Hinge Region of the Experimental Study of Shear Capacity of Necessity In the Seismic Design of Bridges

According to the current domestic and foreign theoretical and experimental results, the plastic hinge regions of shear ability and concrete materials, section size, shear span ratio, axial pressure ratio, stirrup ratio, longitudinal reinforcement rate, displacement ductility and is related to many factors. Therefore, in order to ensure the reinforced concrete bridge piers under earthquake does not appear shear failure, these factors need to conduct a comprehensive study to establish a calculated shear strength plastic hinge zone reasonable formula.

At present, there are some different theories and formulas, however, due to complexity of the problem, influenced by many factors, there are considerable differences among the various expressions. All kinds of expressions are in good agreement with the experimental data, but the results are often given for the same engineering examples.

Figure 2. Seismic Performance of Reinforced Concrete Pier

The formula used in the specification of our country for calculating the shear strength of plastic hinge region is a reference to the shear resistance formula of California earthquake resistant design criterion (2000 EDITION).

And the formula is simplified. only considering the shear strength of concrete and stirrups provided. Compared with other countries caused specifications, calculations are somewhat conservative, resulting in excessive design with stirrups,not only wasteful of material on to a certain extent, but caused difficulties on the design and construction. Therefore, it is necessary to amend the relevant provisions of the rules, make the calculation formula of the pier plastic hinge zone shear strength is more reasonable.

4. Conclusion

In recent years, the research on the seismic behavior of reinforced concrete pier column is strengthened. The more research object is for the reinforced concrete frame column. The research on the pier is less, and more rectangular cross section.

In the study of frame column, mainly concentrated in the axial compression ratio, stirrup ratio and shear span factors influence etc. Therefore, it is necessary to amend the relevant provisions of the rules, so that the calculation formula of the shear strength of the pier plastic hinge region is more reasonable.

In the future research, the failure mode of the reinforced concrete pier column plastic hinge region is studied in the following aspects:(1) Research on failure mode of reinforced concrete pier column plastic hinge region, The failure patterns of plastic hinge region of different specimens under different experimental conditions are summarized and classified. The failure mode and the hysteretic behavior of the reinforced concrete pier are summarized.(2) Study on mechanism of shear resistance of reinforced concrete pier column plastic hinge region. Based on pseudo static test results, the influence of axial compression ratio, ductility factor and other parameters on the shear carrying capacity is analyzed, and the contribution and distribution law of the impact factors on the shear capacity of plastic hinge region are investigated. Combined with the corresponding failure mode, the shear mechanism of reinforced concrete pier column plastic hinge region is studied.

Study on shear capacity of reinforced concrete pier column plastic hinge region. According to the aforementioned plastic hinge zone failure mode and shear mechanism research, combined with the current domestic and foreign research results, on the plastic hinge region shear strength expression makes a comparative analysis on, preferred or re-raise a set of scientific rational plastic hinge regions shear strength expression form. Then, On the basis of this expression, the calculation of shear capacity of plastic hinge region is systematically studied. Finally obtains standard plastic hinge shear strength calculation formula which suitable for practical engineering.

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