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Effect of second coming earthquake's waveform on dynamic behavior of repaired reinforced concrete bridge piers

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ABSTRACT: The purpose of this study is to examine the effect of second coming earthquake's waveform on dynamic behavior of repaired reinforced concrete bridge piers. The experiments were carried out to determine the hysteretic characteristics under dynamic loading using a shaking table. The experimental factors were the degree of damage caused by a primary earthquake and the sizes of initial displacement under the second coming earthquake. Based on the results of this study, the authors concluded that the response of repaired reinforced concrete bridge pier varied with the waveform of the second coming earthquake and was influenced by the initial displacement under the second coming earthquake.

1 INTRODUCTION

When reinforced concrete bridge piers in a seismic zone are damaged by earthquakes, they are expected to be restored rapidly so that transportation in the affected zone can be recovered. If the damage of bridge pier is not severe, repair of only the damaged part is more favorable than reconstruction taking into consideration the time involved and economical factor. The method to repair reinforced concrete bridge piers according to the degree of damage is stated in the manual of counter-measure to earthquake for highway structures (see Japan Highway Association (1988)).

In the authors' earlier research on the displacement of epoxy resin repaired reinforced concrete bridge piers suffering a second earthquake, the authors found that when the waveform was El-Centro earthquake, the response behavior of repaired reinforced concrete bridge pier to the second coming earthquake varied with the degree of damage inflicted in the first earthquake (see Shima (1989)). However, when the waveform was amplifying wave, the earthquake behavior before and after the repair was found to have little difference (see Yokoi (1990)).

Therefore, the purpose of this study is to examine the effect of second coming earthquake's waveform on dynamic behavior of repaired reinforced concrete bridge piers. The experimental factors were the degree of damage caused by the first earthquake and the size of initial displacement under the second coming earthquake.

2 EXPERIMENT

2.1 Experimental condition

The degree of damage is the main parameter in this study. Nine original specimens were tested. The degree of damage were varied three types by changing maximum displacement of the shaking table as primary loading as given in Table 1. After repairing the specimens with epoxy resin, various sizes of initial displacement were applied to the repaired specimens as the secondary loading.

2.2 Specimen

The specimens were approximately one eighth reduced scale model of a single column type bridge pier with a square cross section. Dimensions of the specimen are shown in Fig.1. Reinforcement ratios of longitudinal reinforcement and transverse reinforcement were 1.70% and 0.049%, respectively. Shear span to effective depth ratio was 3.8 because loading point was 20mm high above the top of the specimen.

2.3 Material

The size of steel and aggregate was one eighth of original size according to the ratio of reduced scale.

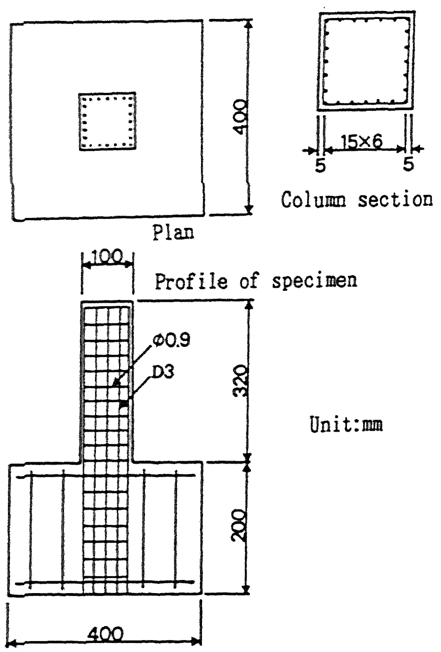

Fig.1 Specimen

Deformed bars having 3mm diameter was used as the longitudinal reinforcement, while mild steel wire having 0.9mm diameter was used as the transverse reinforcement. Mortar with maximum size of aggregate, 2.5mm was used.

Yield strength and tensile strength of D3 deformed bar were 296MPa and 456MPa, respectively. Tensile strength of mild steel wire was 395MPa. Compressive strength of the mortar of each specimen was between 31MPa and 33MPa.

Two types of epoxy resin were used for sealing and grouting in the repair of specimens.

2.4 Loading and measurement

A shaking table was used as shown in Fig.2. A weight having mass of 9.8kN was fixed on the top of specimen. And the weight was fixed to the jack. The mass of weight was applied as axial stress to the specimen, which is 0.92MPa.

The waveform in the primary loading is shown in Fig.3 which was sinusoidal amplifying wave. The amplitude of displacement was increased at an increment of the yield displacement (δy) accordingly. The yield displacement defined as displacement at the top of the specimen when the tension bar at first had yielded. The yield displacement was calculated by taking the rotation at fixed end of the pier into consideration.

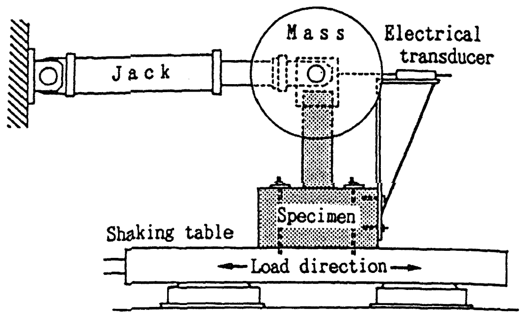

Fig.2 Loading system

The rotation was caused by the pullout of the reinforcing bars anchored in the footing (see Niwa (1985)). The degrees of damage in the primary loading were flexural crack, shear crack and the spalling of the cover concrete by varying the size of the maximum displacement (nδy). The waveform of the secondary loading was shown in Fig.4 which has three types of initial displacement (δp) to examine the influence of waveform. The plasticity ratio (n), which is the ratio of the response displacement to the yield displacement, in the primary loading and the initial displacement (δp) in the secondary loading are shown in the Table 1. The maximum displacement in the secondary loading was 12δy. The acceleration rate at loading was determined by considering the natural period of reduced specimens (see Japan Society of Civil Engineers (1989)).

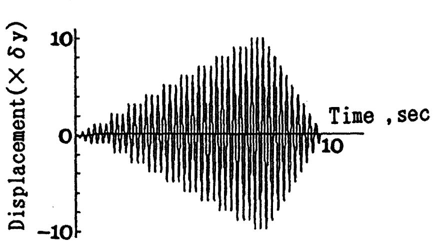

Fig.3 Waveform in the primary loading (Maximum displacement = 10δy)

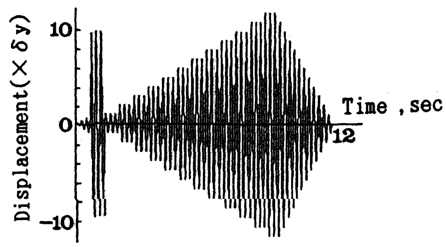

Fig.4 Waveform in the secondary loading (Initial displacement = 10δy)

The relative displacement of the specimen at loading point to the shaking table was measured by using electrical transducers. The loading force was measured by the jack joined to the top of the specimens. The analog data were converted into digital and recorded by a personal computer at an interval of 0.005sec . In order to observe the failure condition at each displacement stage, the loading conditions were recorded on a video recorder.

Table 1 Loading level

Specimen	No.	1	2	3	4	5	6	7	8	9
Primary loading	Maximum(n)	6	6	6	8	8	8	10	10	10
Secondary loading	Initial(n)	6	8	10	6	8	10	6	8	10
	Maximum(n)	12	12	12	12	12	12	12	12	12

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

3.1 Degrees of damage in the primary loading

The degrees of damage in the primary loading were classified into three types of damage which were flexural crack, shear crack and the spalling of the cover concrete. The degrees of damage were shown in Fig.5.

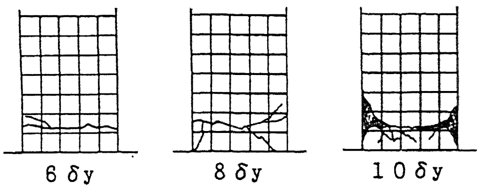

Fig.5 Cracking and failure pattern of three types of damage

3.2 Load-displacement curve

An example of the load- displacement curve in the primary loading to study the hysteretic behavior after repair was shown in Fig.6. And an example of the load-displacement curve in the secondary loading was shown in Fig.7.

3.3 Hysteretic behavior in the secondary loading

In order to study the influence of the degree of damage in the primary loading and the size of the initial displacement on the hysteretic behavior in the secondary loading, the load decline ratio which is the ratio of the maximum load in the amplifying wave to the load at the initial displacement, the stiffness and the load carrying capacity which is the ratio of the maximum load in the primary loading to the secondary was investigated.

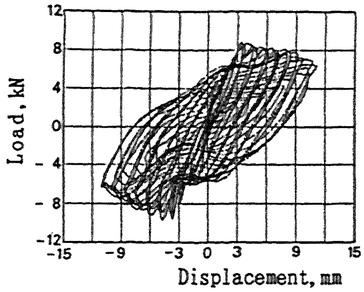

Fig.6 Load-displacement curve in the primary loading

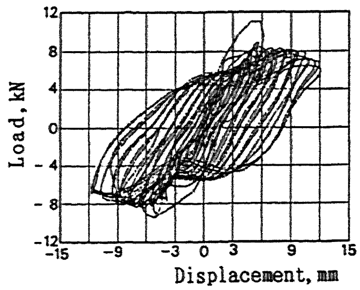

Fig.7 Load-displacement curve in the secondary loading

3.3.1 Load decline ratio

The relationship between the load decline ratio and the plasticity in the primary loading was shown in Fig.8. The load decline ratio was represented by the force ratio (P1max/Ppmax) which was the ratio of the maximum load (P1max) in the amplifying wave to the maximum load (Ppmax) at the initial displacement (δp) in the secondary loading. The load decline ratio increased as the initial displacement and the degree of damage in the primary loading increased.

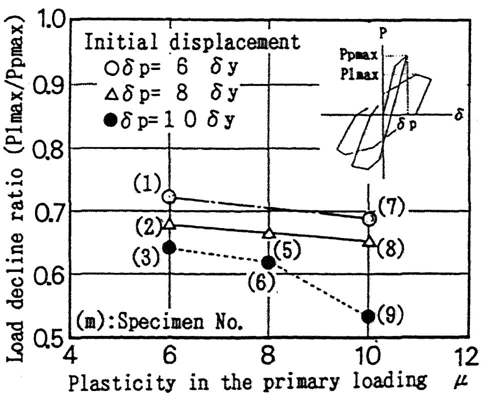

Fig.8 Load decline ratio-plasticity ratio relationship

3.3.2 Stiffness

An example (the degree of damage in the primary loading was 10δy) of the relationship between the stiffness for various initial displacements and the plasticity in the secondary loading was shown in Fig.9. The stiffness was represented by the slope of the maximum loading point on the load-displacement curve and the origin. When the plasticity ratio in the secondary loading was smaller than 9 (i.e. the displacement of the top of pier was 9δy), the stiffness was varied with the waveform in the secondary loading, and the stiffness decreased with increase in the initial displacement (δp). When the plasticity ratio was larger than 9, the stiffness was similarity independent of the initial displacement. This reason is that the effectiveness of repair is decreased by the bonding failure of epoxy resin in 9.

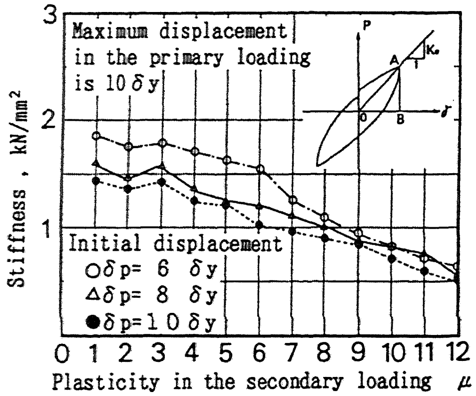

Fig.9 Stiffness–plasticity ratio relationship

3.3.3 Ratio of the maximum load carrying capacity

The relationship between the ratio of the maximum load carrying capacity and the plasticity in the primary loading was shown in Fig.10.

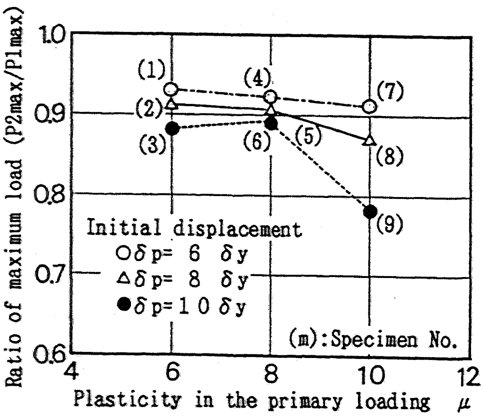

Fig.10 Ratio of maximum load carrying capacity –plasticity ratio relationship

The ratio of the maximum load carrying capacity was represented by the maximum force ratio (P2max/P1max) which was the ratio of the maximum force (P2max) in the secondary loading to the maximum force (P1max) in the primary loading. The ratio of the maximum load carrying capacity increased with increase in the initial displacement (δp). Therefore, the maximum force of the secondary loading is influenced by the waveform of the secondary loading.

4 CONCLUTION

The behavior of repaired reinforced concrete bridge piers varied with the waveform of a second coming earthquake, and it was influenced by the initial displacement under the second coming earthquake.

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