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LOAD BEARING CAPACITIES OF STEEL BRIDGE PIERS SUBJECTED TO LONG-DURATION TIME MOTIONS

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ABSTRACT

Recently, in Japan, long-period and long-duration time seismic waves have been observed, such as Tokachi-Oki earthquake and Niigataken-Chuetu earthquake, and so on. Moreover, there is concern that strong ground motions are generated in the near term by huge ocean-trench earthquakes, such as Nankai earthquake, Tonankai earthquake and Tokai earthquake. It is thought that the strong motions caused by huge ocean-trench earthquakes are long-period and long-duration time seismic waves. However, seismic performances of structures subjected to long-duration time seismic waves are not clear. In seismic design codes in Japan, there are no specific descriptions concerned with the seismic performance of structure subjected to long-duration time waves. Therefore, in this study, cyclic load carrying tests and a pseudo-dynamic test were carried out in order to investigate the cyclic load bearing capacity of steel bridge piers. Consequently, it is found that the load bearing capacity after the maximum load is decrease about 10% due to cyclic loading over 10times and that the cyclic loading history over 100 times are caused.

Introduction

Because huge ocean-trench earthquakes are anticipated in the Nankai, Tonankai, and Tokai areas, we must urgently investigate the dynamic reactions of structures to these huge tremors. The seismic waves of such earthquakes are expected to have a long period and long duration.

In fact, seismic waves having a long period and long duration have been observed quite recently. For example, long-period seismic waves observed during the Tokachi–Oki earthquake (2003) were believed to have caused a hazardous sloshing phenomenon in an oil tank. Furthermore, in Niigata-ken–Chuetu earthquake (2004), seismic waves of long period and long duration affected many structures on the Kanto Plain.

While considering seismic waves of type 1 and type 2 defined in specifications for highway bridges, elasto-plastic and buckling characteristics of steel bridge piers have been accumulated

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sufficient knowledge after performing many investigations of their deformation behavior (Chen et. al. 2007, Usami et. al. 1993 and Kodama et. al. 2003). In addition, research into the behavior of long-period structures subjected to long-period seismic motion during earthquakes has been simulated (Nii et. al. 2005). Nevertheless, little is known about the behavior of steel piers that are used widely for urban elevated bridges when subjected to seismic waves having a long period and long duration.

For this study, monotonic and cyclic tests were carried out to examine the load-bearing quality of steel used widely for bridge piers in urban elevated bridges when they are subjected to long-duration seismic forces. The loading pattern applied to piers during our tests subjected them to hysteretic major motion around the maximum load first, followed by a long-duration cyclic seismic force of amplitude to the elastic limit, which was applied for several tens of repetitions. The effect of the cyclic force, repeated several tens of times, on the load bearing quality of piers is the main objective of this study.

Additionally, hybrid test using the modeled oscillating system with one degree of freedom was performed. An artificial seismic wave simulating a long-period, long-duration wave was used as the input for hybrid tests. The duration was set to 150 s. Our hybrid tests were conducted to confirm the soundness of the cyclic loading pattern in tests stated in the preceding paragraph.

Outline of Experiment

Material Test

Tensile tests were carried out to determine the yielding point and stress–strain relation of the steel used for the bridge pier test specimen. Three test specimens for tensile tests were made from SS400 steel for experimental bridge piers. The yielding point shown below is the average of data for three specimens. Fig. 1 demonstrates the stress–strain relation inferred from the test results. Table 1 presents the mechanical properties that were observed.

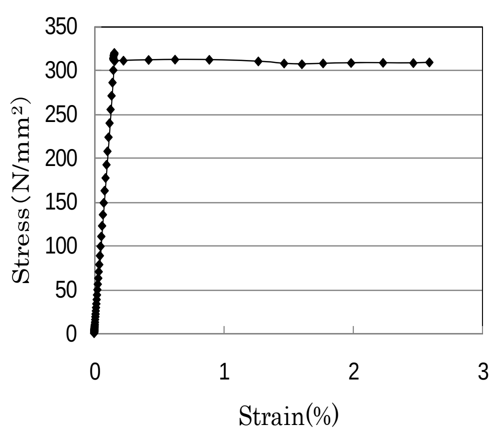


Figure1. Stress-strain curve.

Table 1. Mechanical properties from test results.

	Average
Yield stress	307.3 (N/mm^2)
Tensile strength	439.6 (N/mm^2)
Young's modulus	201900 (N/mm^2)
Poisson's ratio	0.29
Elongation	36 (%)

Specimens

We designed an experimental bridge pier (specimen) modeled on an existing steel bridge pier to fabricate a one-eighth sized model. It simulates bridge piers of about 10 m height most widely used in urban expressways. Particular attention was devoted to the width–thickness ratio of stiffening panel, the width–thickness ratio of the panel attached between vertical stiffening panel, the width–thickness ratio of the vertical stiffening panel as outstanding plate, and the slenderness ratio of the column, representing its strength as parameters that influence the bridge pier's load-bearing capacity and deformation behavior. Values of these parameters were common to the specimen and existing bridge pier.

The mechanical specifications and buckling parameters of the specimen are listed, respectively, in Table 2. The height and width of the specimen satisfying Table 3 are, respectively, 262 mm and 372 mm. The height and thickness of the stiffening material are, respectively, 21.5 mm and 6 mm. Fig. 2 depicts a side view (left panel) and cross-section (right panel) of the specimen.

Table 2. Structural properties of specimen.

Cross section	7464 mm^2
2nd moment of area	8678×10^4 mm^4
Yield stress	307.3 N/mm^2
Axial force	2256×10^2 N
Young's modulus	2019×10^2 N/mm^2
Yield horizontal Force	1168×10^2 N
Yield displacement	8.6 mm
Width–thickness parameter of flange	0.615
Slenderness parameter	0.362

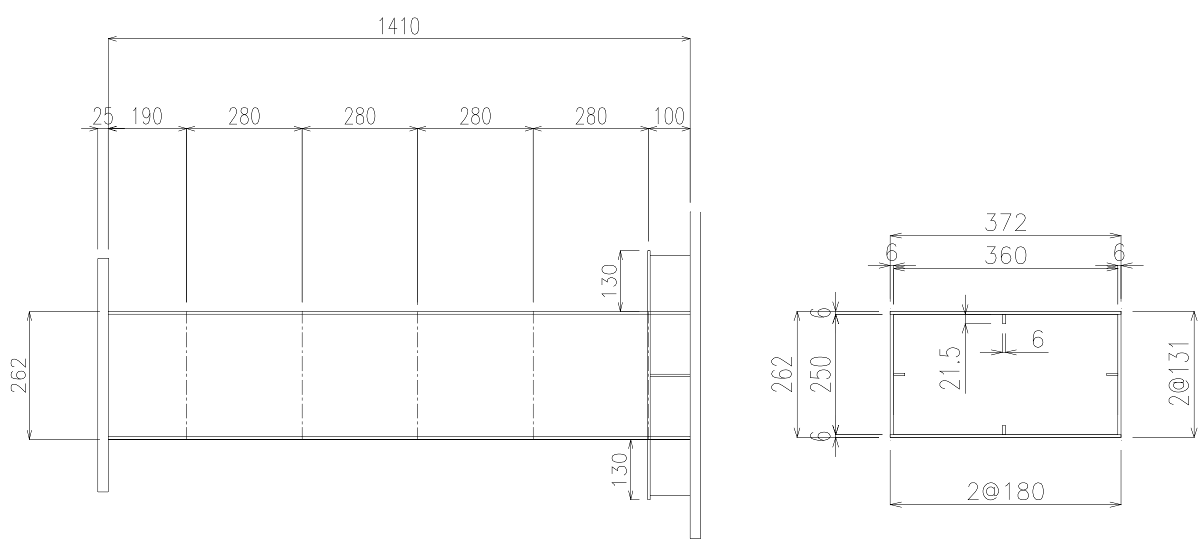


Figure 2. Side view and cross section of specimen (unit: mm).

Loading Apparatus and Procedure

Static monotonic loading tests and cyclic loading tests with increasing amplitude were conducted to examine the load-bearing capacity of the steel bridge pier. The experimental setup is depicted in Fig. 3 and Photo. 1. In both tests, a vertical dead load was applied as the axial thrust equivalent to the load working on the upper structure of the pier. The hydraulic jack prepared for the test is of a constant pressure type. Its maximum load is 100 kN; its stroke is 150 mm. The horizontal load was applied as forced displacement by a displacement control type actuator providing 500 kN maximum load and stroke of ±150 mm. An angle jig at the base portion of the setup was attached to release rotation there when the displacement was measured. See Photo. 1 and Fig. 3. Eight strain gauges were put on the upper and lower sides of specimen at distances of 140 mm and 420 mm from the base. Static monotonic loading tests were terminated when the load decreased to some 80% of the maximum load.

In cyclic loading tests with increasing amplitude, we applied forced displacements with reference to the displacement at yielding point δ_y. Fig. 4 shows that displacements of $\pm 0.6\delta_y$, $\pm 1.2\delta_y$, $\pm 1.8\delta_y$, $\pm 2.5\delta_y$ and $\pm 3.0\delta_y$ were given each three times first. Then displacement of $1.0\delta_y$-$3.0\delta_y$ was applied 10 times. This displacement was determined from the finding that the strength of the specimen was about 90% of the maximum strength of that at $3.0\delta_y$. All displacements are target displacements in this context. The pattern of loading was obtained from our analyses of the time history response of a huge ocean-trench earthquake. Regarding the time history, the steel bridge pier experiences a displacement that is greater than the displacement corresponding to the maximum load first. It then suffers from cyclic loading within the elastic limit. Our loading pattern simulates this time history. In huge ocean-trench earthquakes, although cyclic loading might continue for several hundreds of seconds and more than several tens of cycles, our repeated loading was limited to 10 cycles.

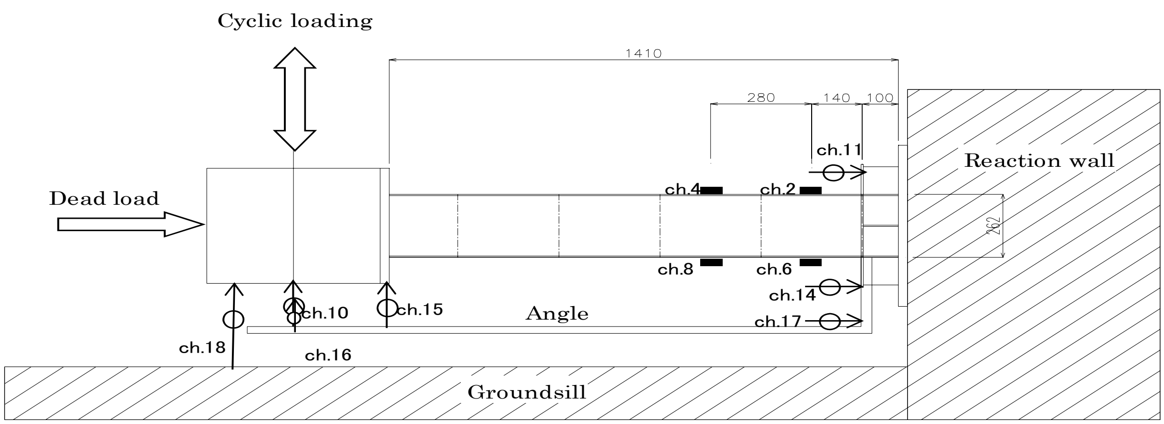
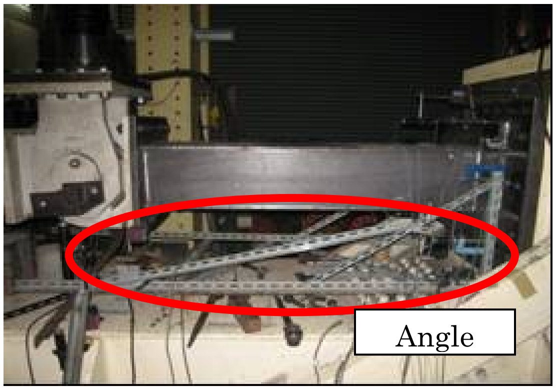


Figure 3. Experimental setup.



Photograph 1. Experimental setup.

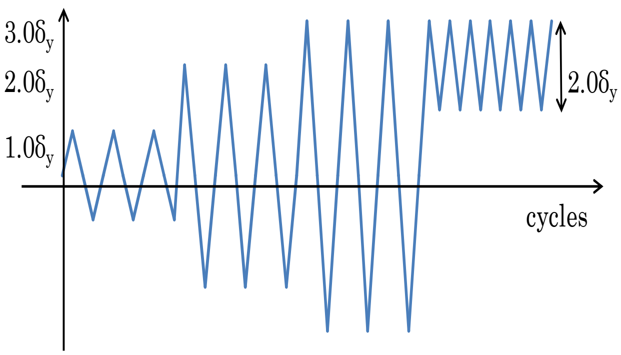


Figure 4. Loading pattern.

Results and Discussions

Monotonic Loading Test

Fig. 5 portrays the horizontal force – horizontal displacement relation inferred from results of the static monotonic loading test. At force – horizontal displacement of 2.79, the horizontal force reaches its maximum of 1.25. From that point, the strength decreases to 1.13 (90%) at displacement of 3.45, and to 1.00 (80%) at displacement of 4.47. This decrease of strength from the maximum strength might be attributed to buckling at the compression side of the flange.

Photo. 2 depicts the base part of the specimen, demonstrating local buckling at the compression side of flange. From this, we can readily verify the occurrence of local buckling after the maximum strength.

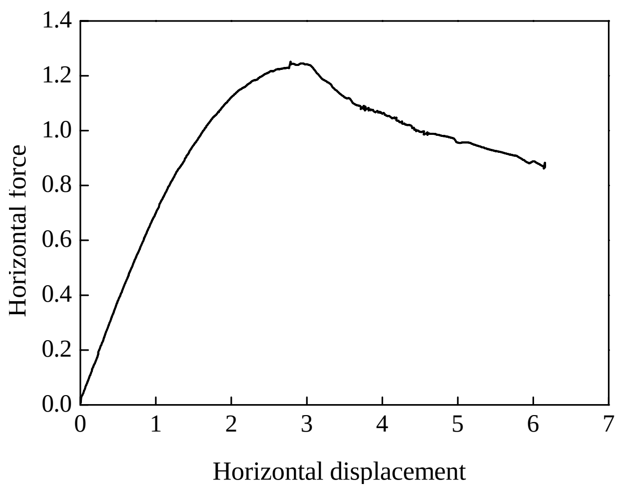
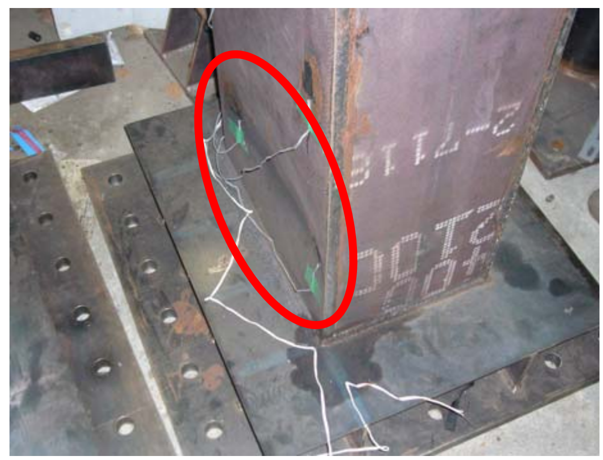


Figure. 5 Horizontal force–displacement curve (monotonic loading).



Photograph 2. Local buckling of flange.

Cyclic Loading Tests

Figure 6 presents the horizontal force – horizontal displacement relation obtained by cyclic loading tests with increasing amplitude. At horizontal displacement of 2.02 , the horizontal force reaches its maximum of 1.05. From that point, the strength decreases at cyclic loadings of $\pm 2.4\delta_y$ and $\pm 3.0\delta_y$ is repeated three times each.

Local buckling was observed after the maximum load of cyclic loading with increasing amplitude test as in the static monotonic loading test. Cyclic loading must have promoted local buckling; we found it in upper and lower sides of the flange and on both sides of the web. Local buckling in cyclic loading was much more severe than that found in the web in static monotonic loading tests.

Fig. 7 presents a magnification of Fig. 6 at around $3.0\delta_y$ of displacement. With great clarity, deterioration of strength is visible after 10 repetitions of cyclic loading within the elastic limit, following maximum loading. In the figure, the horizontal load was reduced from 0.80 to 0.73, with some 10% reduction of strength.

Although we did not expect a marked reduction of strength for displacement within the elastic limit, it did occur after experiencing cyclic loading of as many as 10 repetitions following buckling caused by the maximum load. Incidentally, no crack was found at welded zones after tests.

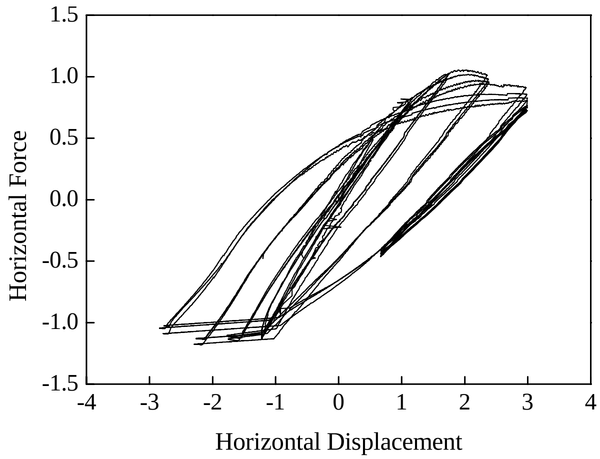


Figure 6. Horizontal force–displacement curve (cyclic loading).

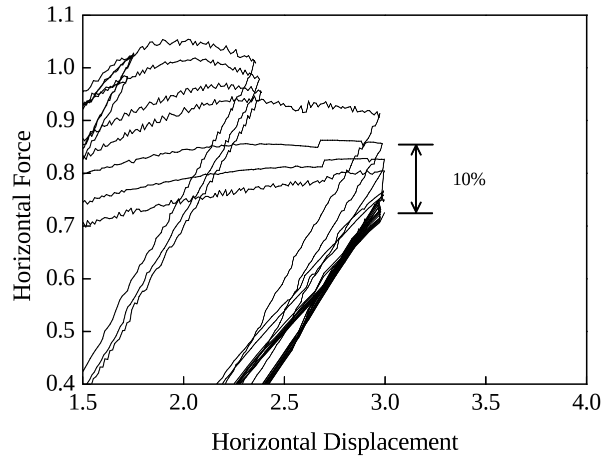


Figure 7. Horizontal force–displacement curve (close up neighboring $3.6\delta_y$).

Hybrid Test

A hybrid test inputting a simulated signal of seismic waves of long period and long duration was conducted. Fig. 8 depicts the seismic wave that was used. The test specimen had the same specifications as those for the specimen of the cyclic loading test. The waveform presented in Fig. 8 is a simulated seismic wave modeled on an imaginary Tokai earthquake1). It has a predominant period around 2.5 s and was input for 150 s in the test.

Figs. 9 and 10 respectively present the time history of the displacement response and load – displacement of the relation inferred from the hybrid test results. In Fig. 9, the abscissa shows the time and the ordinate shows the displacement response. In Fig. 10, the abscissa is the displacement response and ordinate load. Fig. 9 depicts the drift of displacement after 40 s; it is a residual displacement with negative drift of some $2\delta_y$.

Furthermore, Fig. 10 shows the maximum load around $2\delta_y$ and the subsequent decrease of the load. That figure suggests that a cyclic displacement encompassing the plastic zone of 0-$3\delta_y$ occurred several tens of repetitions. This is a severer loading than that in the cyclic loading test presented above.

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Conclusions

Structures are known to suffer cyclic loading with a long period for long duration in huge ocean-trench earthquakes. Experiments of two types were conducted to examine the effects of these loads on the strength of a steel bridge pier. One was a cyclic loading test with increasing amplitude. Another was a hybrid test inputting a seismic wave signal of long period and long duration. Reduction of strength by some 10% after several tens of repetitions of cyclic loading within elastic limits was estimated. Local buckling was found in the flanges and webs of specimens after testing. The hybrid test suggested the occurrence of a cyclic displacement encompassing the plastic zone of 0-3δ_y for several tens of repetitions. This might constitute severer loading than that in our cyclic loading test.

We will undertake further experiments using specimens with different structural properties to examine the reduction of strength and rigidity attributable to cyclic loading following maximum loading.

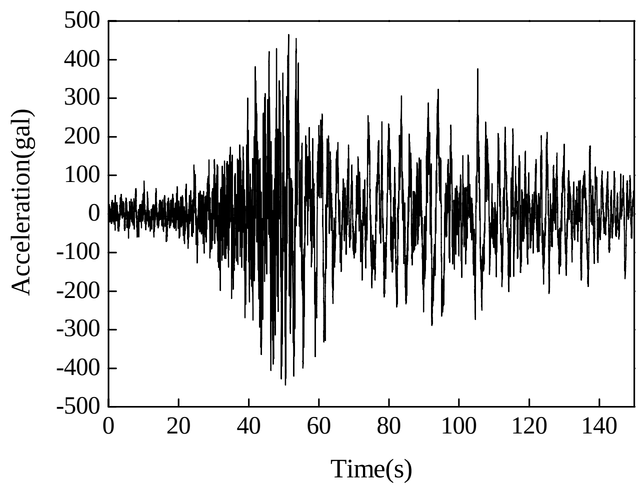
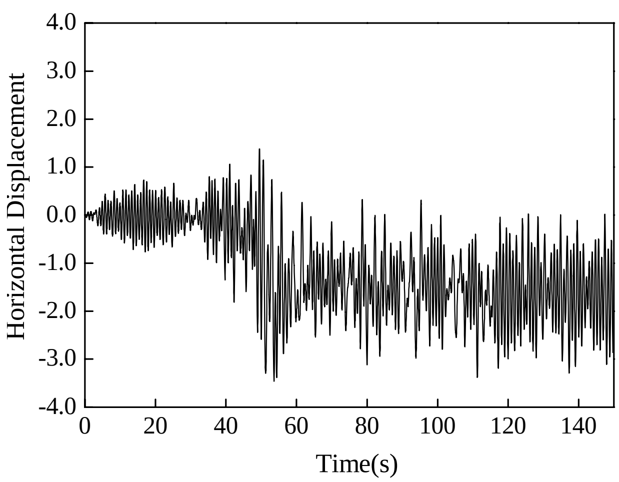


Figure 8. Input seismic wave.



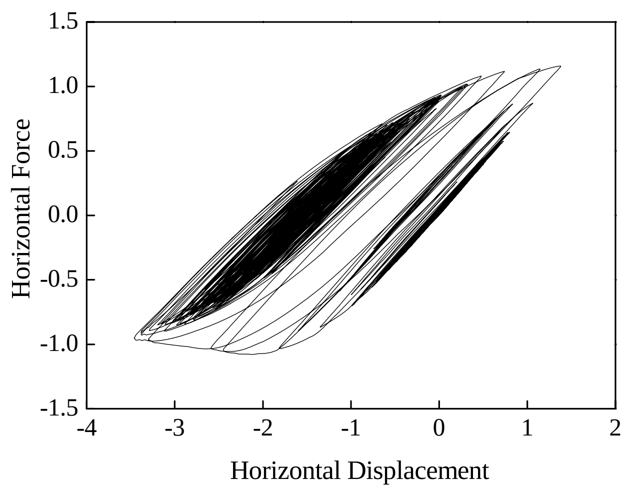


Figure 9. Time history of displacement response. Figure 10. Horizontal force-displacement curve.

Acknowledgments

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