Field Experiment on a Damping Characteristic of Actual Container Cranes

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SUMMARY:
In the seismic design of container cranes, numerical calculation was introduced and more detailed examination has come to be performed in performance-based design procedure. In order to investigate the damping property of containers crane at port areas, an actual container crane was excited with the dynamic loading apparatus consisting of a hydraulic power unit, accumulators, and an actuator. The excitation apparatus was connected to a container crane with a carbon rope because of light and easy handling; the weight of about 60m is only 10kg. The crane was subjected to cyclic loading at the same period with the natural periods in the transverse direction. The damping factor of the crane was assessed from the decrease of amplitude during free vibration after the cyclic loading.

Keywords: container crane, damping characteristic, field experiment

1. INTRUDUCTION

Since most of the container cranes in Kobe port were seriously damaged during 1995 Hyogoken-Nambu Earthquake, many seismic technologies had been developed to improve the seismic performance of container cranes. In the seismic design of container cranes, numerical calculation was introduced and more detailed examination has come to be performed in performance-based design procedure. In the three-dimensional frame analysis for the current container crane design, 0.025 of the damping factor is generally employed according to the steel bridges design in Japan and, however, their actual damping property has not been clarified.

In order to investigate the damping property of containers crane at port areas, an actual container crane was excited by the developed device which consists of a hydraulic power unit, accumulators, and an actuator. The crane was subjected to cyclic loading at the same period with the natural periods and damping factor was assessed in this research.

2. TEST METHOD

2.1. Investigation methods previously employed

The methods summarized in Table 2.1 have been employed in researches to date in order to examine vibration property of gantry cranes. Microtremor observation is convenient way to inspect natural frequency of structures and frequently employed in practical work. But microtremor is too tiny vibration to inquire damping property of structures. Excitation with operation is a method typical to cranes which can move by themselves. Excitation in travel direction conducted with crane travelling and sudden braking is easy to vibrate itself. However, it is difficult to excite itself in traverse direction which is most important direction for instability of cranes. Traversing of trolley and spreader can excite a crane in traverse direction but it is difficult to excite large vibration enough to inquire damping property.

Focusing on seismic performance of a container crane, vibration in the traverse direction has large influence to its instability. About performance of a quay wall associated with that of a container crane, direction vertical to the face line is most concerned to their instability during earthquake excitation. Therefore excitation in the traverse direction in a certain level for damping behavior of a crane is examined in this research.

Table 2.1. Research Methods to Investigate Vibration Property of Container Cranes in Existing Investigations

Method	Details
Microtremor observation	Observe microtremor on a crane with a seismometer Conduct frequency analysis to identify natural frequency of the crane Cannot inquire damping property
Excitation with trolley and spreader traversing	Excite a crane with its trolley and spreader traversing and observe following free vibration with a seismometer Conduct frequency analysis to identify natural frequency of the crane Difficult to excite large vibration enough to inquire damping property
Excitation with crane travelling	Excite a crane with its travelling and sudden braking and observe following free vibration with a seismometer Conduct frequency analysis to identify natural frequency of the crane Difficult to excite vibration and to inquire vibration mode in traverse direction
Strong earthquake motion observation	Observe strong earthquake motion with a seismometer Conduct frequency analysis to identify natural frequency of the crane Conduct numerical calculation and calibrate a numerical model with mass, stiffness, damping, etc Uncertain to obtain strong motion records

2.2. Test method

Vibrators with eccentric weight rotation are usually used to investigate vibration property of structures. The vibrators are generally heavy. As container cranes don't have broad space on themselves in usual, it is difficult that the heavy vibrator is mounted on cranes. Lifting a heavy vibrator up to a high portion of a crane is also hard to perform. Accordingly, the method of tugging cranes with a device on the ground is examined in this research.

In order to vibrate a container crane in a certain level to obtain its damping behavior, the following test method is examined; the container crane is excited by periodical actuator tugging and releasing corresponding to the natural period of the crane and forced into free vibration after the excitation. Periodical excitation is employed in order to achieve a certain level vibration for the free damped vibration. Natural period of a crane is investigated in advance by microtremor observation on the crane and frequency analysis of the observed microtremor data (see Figs. 2.1 and 2.2). Testing device whose specifications are indicated in Table 2.2 is developed to tug the crane from the ground. It consists of an actuator, accumulators, a power source and a control device as shown in Fig. 2.3.

Actuator is a main component for the test to tug a crane. Accumulators support the power source for sudden hydraulic demand during operation. Figures 2.4 shows a schematic of arrangement of the testing device and its connection to a container crane. Figures 2.5 shows a miniature to explain general view of testing. The testing device is located on the ground and a plate with the actuator is trodden by two trucks in order not to slip during tugging a crane, as shown in Fig 2.6.

Necessary length of cable for the test is about 60m since tie beam where cable is connected to is usually placed at high position of a crane about 40-50m from the ground. A metal cable with of about 60m in length generally has to heavy weight to handle it. Accordingly, carbon cable shown in Fig. 2.7 is utilized for easy handling; the carbon cable is manually pulled up to connecting position of the crane because of lighter weight than metal cable. The carbon cable of 60m in length weighs only about 10kg. Carbon fiber is weak for bending but as strong as steal material in tension.

A section of the tie beam often has flanges as I-shaped section. In this situation, protection of connected portion of crane tie beam is necessary and protective equipment is utilized in this research: sling and metal protector shown in Fig 2.8. Figure 2.9 shows the entire circumstances during the testing.

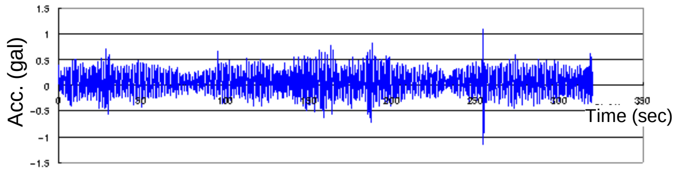

Figure 2.1. Result of microtremor observation

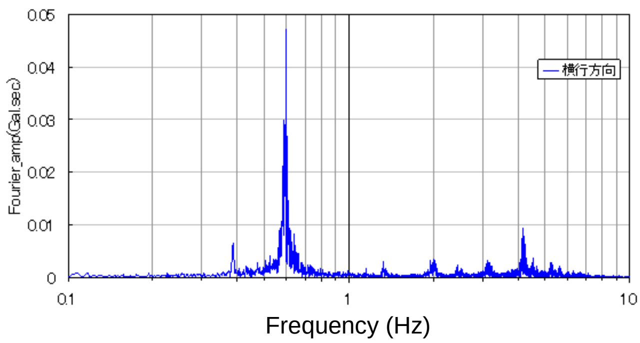

Figure 2.2. Fourier spectrum of microtremor acceleration

Table 3.2. Specifications of testing device

Actuator	
Maximum force	30kN
Stroke length	1400mm
Frequency	0.1-1Hz (1-10sec in period)
Power source	Hydraulic power source 20MPa 15kW
Load cell	
Type	Strain gauge type transducer
Capacity	50kN
Measuring accuracy	±1%
Ingress protection rating	IP-68
Amplifier	alternating current system
Output	±5V
Displacement transducer	
Type	
Capacity	1500mm
Nonlinearity	0.025%RO
Resolution	0.01%RO
Hysteresis	±0.01%
Ingress protection rating	IP-68
Output	±5V
Traction cable	
Sling connected to tie beam of crane	Polyarylate textile, maximum working load: 50kN
Main cable	Carbon fiber cable, breaking load: 170kN
Cable connected to actuator cylinder	Metal cable, breaking load: 170kN
Emergency stop device	
Operation	automatic (load: 30kN), manual
Weight	
Main unit	about 1500kg
Hydraulic power source	about 1500kg
Accumulator	about 500kg (120l), about 200kg (50l)
Control device	about 35kg

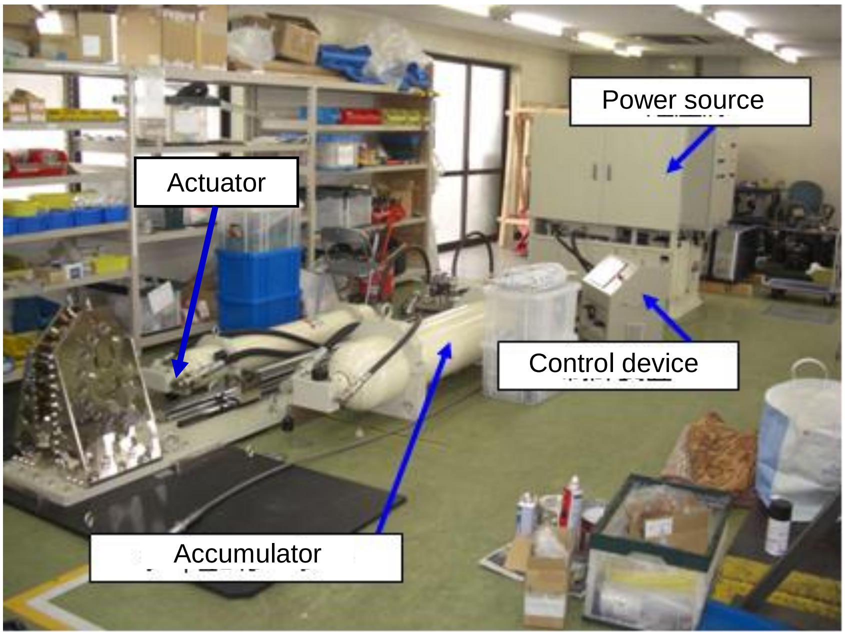

Figure 2.3. Developed testing device

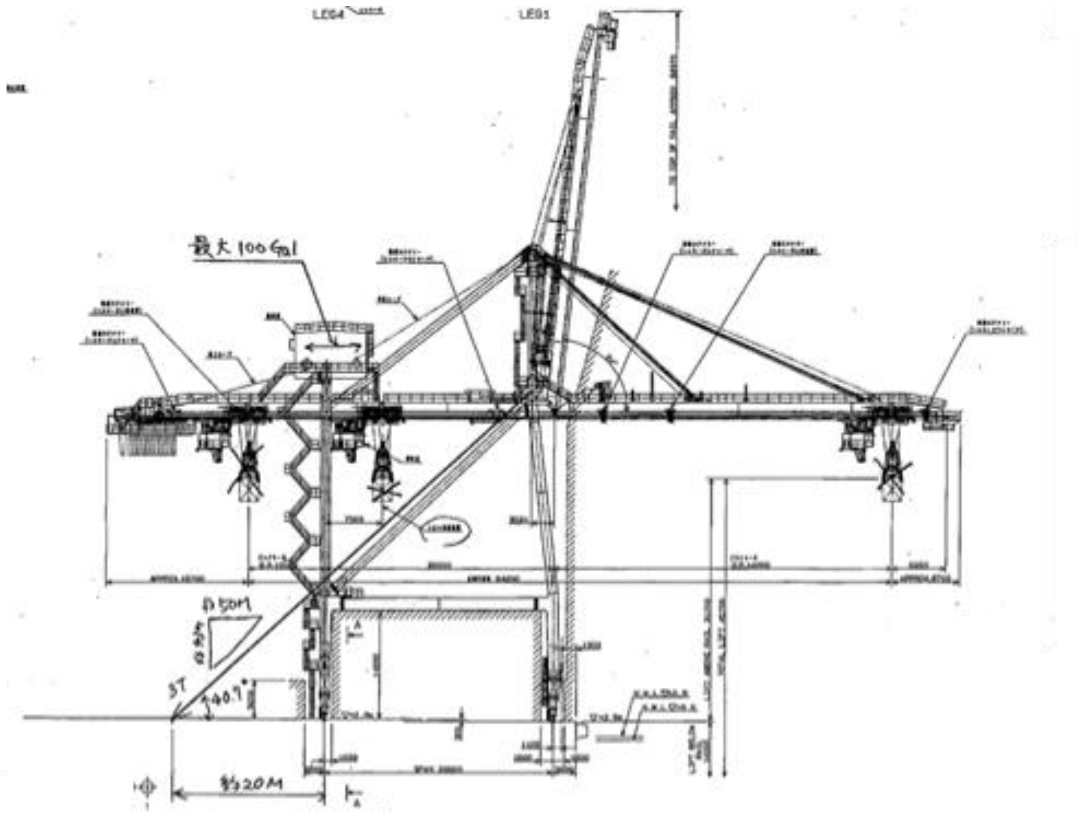

Figure 2.4 Schematic of arrangement of the testing device and its connection to a container crane

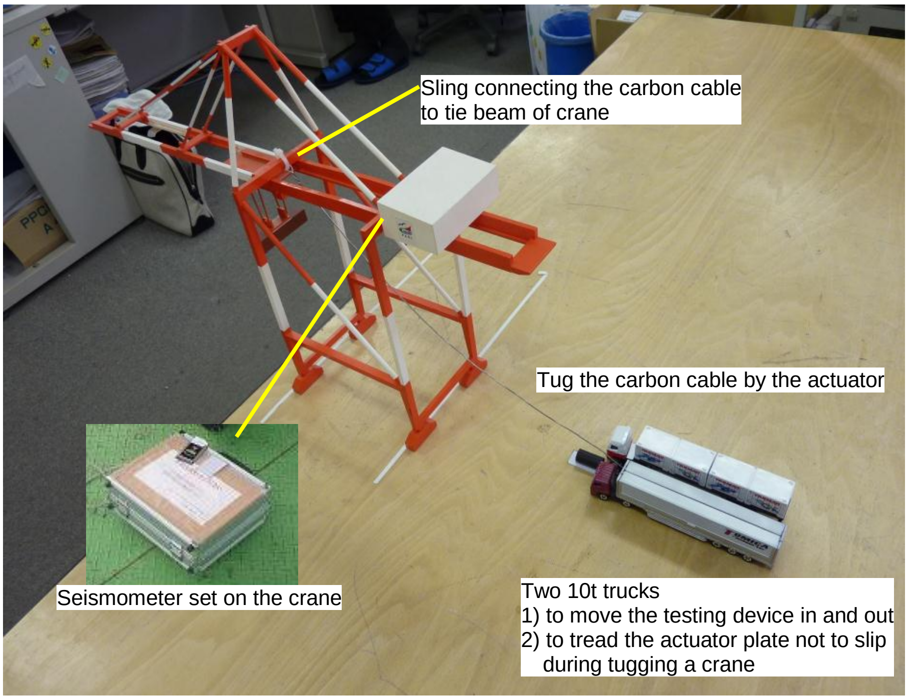

Figure 2.5. Miniature to explain general view of testing

Figure 2.6. Actuator fixed with two trucks treading

Figure 2.7. Carbon fiber cable

Figure 2.8. Protective equipment of connected portion

Figure 2.9. Entire circumstances of the test
(a): side view, **(b):** back view

3. TEST RESULTS

A container crane is excited by the actuator with force control and automatic stop system by exceeding 30kN in force is introduced. Besides, the excitation is manually interrupted not to damage the crane when its acceleration exceeds 100gal.

The crane is initially tugged with initial tensile load and fluctuated with predefined amplitude of load. An acceleration time history as the test result and envelope fit to the damping behaviour are shown in Fig. 3.1. From this figure it is found that damping factor of 0.4% is appropriate to this container crane. Figure 3.2 shows damping factor as results of all test cases varying load magnitude. The horizontal and vertical axes indicate a wave number in free vibration and mean damping factor during the following ten waves, respectively. It is recognized that damping factor is around 0.2-0.4% and less than 2.5% as for general steel structures. It is considered that acceleration amplitude of less than 50gal is small and larger damping might be for larger vibration of cranes.

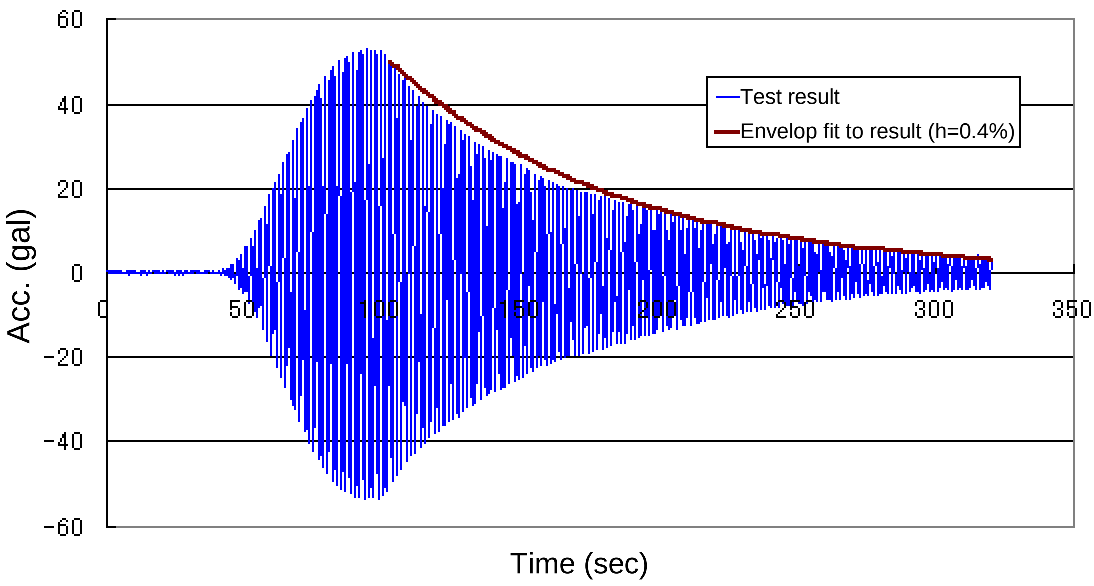

Figure 3.1. Acceleration time history during free vibration

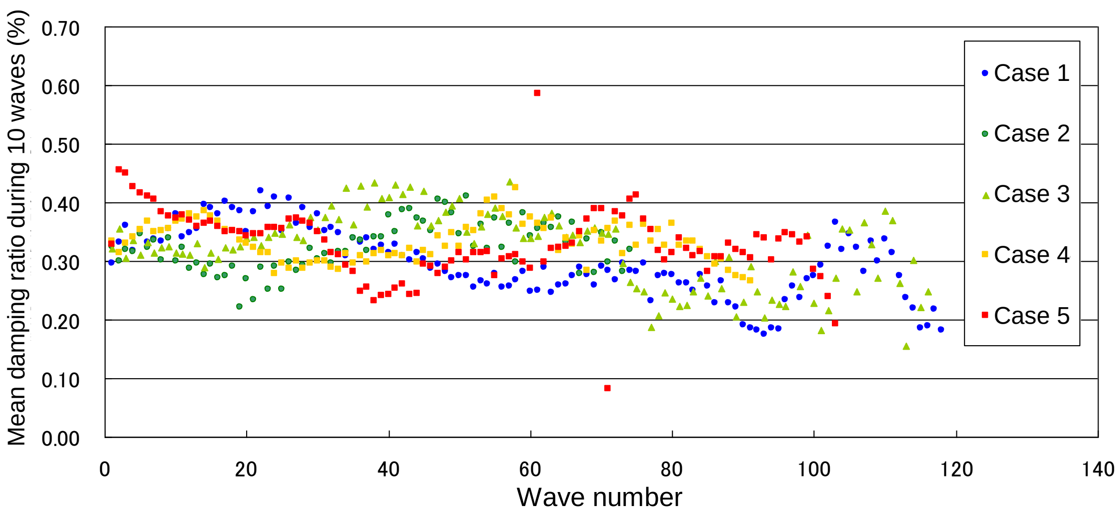

Figure 3.2. Damping factor

4. CONCRUDING REMARKS

In order to investigate the damping property of containers crane at port areas, an actual container crane was excited with the developed dynamic loading apparatus consisting of a hydraulic power unit, accumulators, and an actuator. The excitation apparatus was connected to a container crane with a carbon rope because of light and easy handling; the weight of about 60m is only 10kg. The rope was manually raised and connected to the tie beam of the crane, at the height of about 40m. The crane was subjected to cyclic loading at the same period with the natural periods in the transverse direction. The damping factor of the crane was assessed from the decrease of amplitude during free vibration after the cyclic loading. From the test results, it is found that damping factor is around 0.2-0.4% and less than 2.5% as for general steel structures. It is considered that acceleration amplitude of less than 50gal in the test is small and larger damping might be for larger vibration of cranes.

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