INTRODUCTION OF RESEARCH & DEVELOPMENT OF THE NEW BIAXIAL UNDERWATER SHAKING MACHINE FOR OCEAN STRUCTURES & APPLICATION TO MODEL TESTS

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SUMMARY

An underwater shaking machine capable of performing biaxial and simultaneous shaking has been developed by the College of Science and Technology of Nihon University in order to investigate experimentally, the dynamic response problems of ocean structures fixed, moored or soft touched to the sea bed induced by earthquakes. The following is an introductory outline of the underwater shaking machine and a description of the vibration test of cylindrical shell model conducted using the machine.

INTRODUCTION

The underwater shaking machine was developed to investigate, through actual physical phenomena, the dynamic behavior of ocean structures in discussing their response problems. The dynamic behavior of the ocean structures are treated as interaction problems between structure and fluid. In the mathematical models of theoretical analysis, the interaction problem is considered by estimating the added mass, damping coefficient, spring constant, and external load in the equation of motion. Regarding structures of complex form, it can be said that their is a limit to obtaining these terms based on the mechanism of water wave motion on a strictly theoretical basis. While there exist numerous papers dealing with the theoretical analysis of vibration problems of ocean structures having elastic and flexible characteristics, there are only a few treatises based on actual experiments.

It is expected that ocean structures will be constructed further out at sea, in greater depths of water, and in increasingly larger size than at the present. In addition, it is believed that their use will diversify, and their form will become more complex, thus making it difficult to deal with their dynamic behavior. Authors have been conducting research and development on a shaking machine in order to grasp the dynamic behavior of the structures subjected to oceanic earthquakes, and hereinafter authors report on the frequency characteristics of the shaking machine and the cases of application to model tests.

OUTLINE OF THE UNDERWATER SHAKING MACHINE

Specification and Design Process

Specifications of the shaking machine were determined by the following factors: (1) Biaxial shaking: capable of applying horizontal and vertical shaking movement independently corresponding to the horizontal and vertical components of seismic waves, and in addition, capable of carrying out biaxial and simultaneous shaking: (2) Reproduced waves: capable of reproducing sinusoidal waves, seismic waves and random waves; and (3) Test model and basin size: a basin, on which the test model is installed, is capable of performing wave making function, which size is 7m in width, 19m in length, and 1.5m in depth. The generated wave period is between 0.3 second and 3 seconds. The maximum size of the test model was determined so that the reflection wave caused by the interaction between the model and basin wall will not occur.

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Regarding the design process, the operational frequency range and acceleration were first established by the aforementioned factors (2) and (3). Then, the required shaking force was decided, which is a force that can be reproduced with high accuracy according to the input signals when the model is placed. The machine is installed in the basin provided with wave making ability. Therefore, reproducibility of combined wave and seismic loads was also considered, and the shaking force capable of resisting the wave was estimated. It is desirable that the actuator of the machine is able to conduct biaxial and simultaneous shaking, and consequently, an electrodynamic type was employed due to mechanical reasons.

The concrete specifications of the shaking machine are shown in Table 1.

Machine Components

The machine system consists of a biaxial shaking machine, control equipments and a basin (Fig. 1). The force generated by the shaking machine is propagated to the model supporting base in water through four shaking bars that extend through the bottom of the basin upwards. Fig. 2 indicates the horizontal and vertical sliding mechanism, and Fig. 3 is a general view of the shaking machine. The shaking principle is indicated in Fig. 4. Fig. 4 (a) illustrates the cross section of the electrodynamic shaker. Shaking force is generated when a moving coil with alternating current is placed in a magnetic field. In Fig. 4(b), two electrodynamic shakers are arranged vertically, whereas in (c), they are placed horizontally. Fig. 4 (d) shows a combination of moving coils that produce a shaking in a horizontal direction and generate a shaking in a vertical direction. These four moving coils are fixed to a shaking frame, which can freely move in both horizontal and vertical directions. Fig. 5 illustrates the details of the shaking machine. Shaking bars that support the testing model protrude into the water from the top of the shaking frame, on which the moving coils are fixed. A rubber seal is installed in the middle of the shaking bars to prevent leakage. The shaking bars are composed of stainless steel square columns, which are 3mm thick, 1300mm long, and 80mm wide. Air springs are installed to maintain a neutral position, both horizontally and vertically.

Control System

The control system consists of a variable phase generator (manufactured by NF Circuit Design Block Co., Ltd., FG-124) and a directional amplifier (Akashi Co., Ltd., TP-1200). The block diagram of the control system is shown in Fig. 6. The variable phase generator capable of generating two types of output signals that can freely adjust phase difference. These two output signals are employed in conducting biaxial and simultaneous shaking under the same frequency, but at different phases.

Vibration Characteristics

Fig. 7 shows the frequency response in the horizontal direction when it is driven at constant voltage, and also Fig. 8 is relating to the vertical direction. Fig. 9 indicates the phase characteristics under biaxial and simultaneous shaking.

The frequency response in the horizontal direction is characterized by the two peaks. When there is no load, resonance occurs at frequencies, 7Hz and 70Hz. Resonance observed at 7Hz is caused by a movable mass (shaking frame, shaking bars, moving coils and test model) and the air spring, while that at 70Hz is caused by the shaking bars.

When a weight of the test model (225kgf) is applied, the resonance frequencies decline. Fig. 9 shows the characteristics during shaking by establishing four different phases for the horizontal and vertical input signals The phase difference can be seen around 10Hz. This is caused by the movable mass and the spring constant, which difference is belong to vertical and horizontal movements. In addition, there are differences between the calculated and experimental values at 40Hz. This is due to the discrepancy in the phase difference caused by the resonance of the shaking bars. The theoretical values indicated in these figures were obtained by equations shown in Ref. 1.