Influence of wave shapes to Tsunami Wave Force Acting on a Bridge Superstructure

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ABSTRACT

In the Tohoku-Pacific Ocean Earthquake, many bridges were washed away by the tsunami. In the future, countermeasure for tsunami disaster will be needed, and the evaluation of tsunami wave force acting on bridges will be very important. This paper discusses the hydrodynamic tsunami-induced force acting on a bridge superstructure based on hydraulic model experiments. The results showed that tsunami wave forces were different according to the shape of tsunami incident wave and it was confirmed that maximum wave forces could be expressed by a function of the wave front slope of tsunami incident wave.

KEY WORDS: tsunami; bridge; steady wave; bore wave; wave force; hydraulic model experiment; wave front slope.

INTRODUCTION

The tsunami accompanying the 2011 earthquake off the Pacific coast of Tohoku that occurred on March 11, 2011 washed away many bridge girders. The loss of these bridges severed major roadways, delaying the urgent transport of supplies and personnel needed for recovery, as well as slowing down the rebuilding of social infrastructures. Thus, the importance of the roles that roads and bridges took for the large-scale disaster with tsunami was further recognized. Given the future possibility of tsunamis caused by massive earthquakes (e.g., in the Nankai Trough), tsunami-induced damage to bridge structures should be appropriately assessed and measures to minimize possible damage should be examined to preserve the network of roads and bridges when tsunami occurs.

With respect to the evaluation of tsunami wave forces acting on structures, results of model experiments by Tanimoto et al. (1984) and Ikeno et al. (2005) on port facilities such as breakwaters have led to tsunami wave force evaluation formulae that have been incorporated into tsunami-resistant design guidelines (2013). Also, in the case of structures such as tsunami evacuation buildings, evaluation formulae are shown in the structural specifications for tsunami evacuation buildings (2012). The formulae are provided by reconsidered the experimental research by Asakura et al. (2000) based on the tsunami damage investigation results following the Great East Japan Earthquake. Meanwhile, in the case of bridges in rivers and estuaries, design standards and methods have not been established yet at present. Although the 2012 revised specifications for highway bridges (2012) calls for clearances between static water surface and bridge girder and implementations of appropriate structural shape, considering the influence by tsunami wave.

Since the 2004 Sumatra-Andaman earthquake and the resulting Indian Ocean tsunami, many studies on tsunami-induced hydrodynamic forces acting on bridges have been performed (Iemura et al., 2007; Araki et al., 2010; Kosa et al., 2010; Kosa et al., 2010; Shoji et al., 2010; Araki et al., 2012; Tonaga et al., 2012; Nakao et al., 2013). In most former research, tsunami wave forces and bridge stability were evaluated for bore waves or short period solitary waves. The authors also have previously evaluated wave forces acting on a bridge superstructure for short period solitary waves, by means of hydraulic model experiments and numerical simulation (Hayashi et al., 2014). However, observation of video images recorded during the approach of the tsunami resulting from the Tohoku Earthquake suggests that, while some bridges were indeed affected by bore wave, other cases were quite different. As recognized in the Utatsu Bridge (Li et al., 2013) and the Kesen Bridge (Jinguji et al., 2014), bore wave at the surge front of the tsunami passed under the bridge girders and didn't act on them, but the long period wave whose water level rose gradually submerged the bridges and washed away them. Therefore, tsunami wave shape acting on a bridge superstructure is not necessarily that of bore wave, but it can be of various types depending on the bridge installation site.

Thus, hydraulic model experiments were conducted to research the influence of wave shapes to tsunami wave forces acting on a bridge superstructure. Horizontal wave force, vertical wave force and hydrodynamic moment of various wave front slopes from the case of a long period solitary wave where the water level rises gradually, to that of bore wave were measured. Furthermore, the difference of force coefficient between tsunami wave and wind was studied by comparing hydrodynamic coefficients calculated based on measured tsunami wave forces and wind coefficients obtained from the estimation formula.