A Study on Stability of Container Cranes during Strong Earthquakes

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Abstract

The seismic design procedure for large container cranes adapting the pseudo-static method as a seismic coefficient of 0.2. The same manner, the pseudo-static method is used against a wind load as a equivalent coefficient of 55 m/s wind velocity. Of the two design factors, the wind resistance turns out to be the determining one in most cases. During the 1995 Hyogoken-Nanmbu Earthquake (The Great Hanshin Earthquake Disaster) the port structures and cargo handling machinery of the Port of Kobe were seriously damaged. Since the serious damages research work, two levels of earthquake motions are used as design reference motions, defined as L1: the level of earthquake motions that are likely to occurred during the life-span of the structure, L2: the level of earthquake motions associated with infrequent rare events, that typically involve very strong ground shaking, the new seismic design concept was announced by the Japan Society of Civil Engineers. To evaluate seismic performance of port structures, dynamic analysis has been introduced to the design code. Reflecting such a revision in earthquake resistance design code for port structures, it has become necessary to include dynamic analysis for L2 seismic motion in the design of cranes so that container cranes may have earthquake resistance level equal to that of port structures. It is necessary to evaluate the performance of port facilities, both port structures and cargo handling facilities. This is because the locking phenomenon was known to have occurred to the cranes in the 1995 Hyogoken-Nanmbu Earthquake as a result of strong earthquake motions and this phenomenon lifted some legs of cranes. This study has been initiated against such a background to analyze stability of container cranes for strong earthquakes, with a view to establishing earthquake resistant design methods of container cranes.

In this study, focused on the container crane installed in container terminal of major Japanese ports. To investigate the dynamic behavior of container crane, model tests and numerical simulations were conducted. In the model tests, the similitude law (i.e. model and prototype crane scaling law) was constructed based on the vibration modes of model and prototype crane as a scale of 1/15. Both static loading tests and dynamic vibration tests were done. The results of experiment indicate that the lifting of legs caused by bending deformation of the legs and by horizontal acceleration. It has also been found out that lifting behavior of legs can be predicted with the maximum horizontal response acceleration at the center of gravity of crane during vibration test, which is coincide with the equivalent static horizontal load at the center of gravity of crane when the legs liftoff state, during the monotonic horizontal loading test(static

test). To consider the effect of input motion wave forms, a series of shake table tests were conducted with four different seismic input motions. The results of this test indicate that the prediction of legs lifting requires studies on the effects of high-frequency wave component in the response acceleration. A series of dynamic vibration tests also clarified behaviors of container cranes during strong earthquakes. To reduce the big response acceleration during big earthquake such as L2, proposed the philosophy of base isolation technique for the container crane.

The study also proposed a simplified numerical analyses regarding a container crane as a single mass-spring model. The simplified model is capable of exhibiting vibration characteristics just before legs lifting takes place, with sufficiently good reproducibility to justify its use in practical design to predict legs lifting to some extent. The study confirmed that the FEM analysis using a Gap element at the legs base of cranes is sufficiently effective for analysis of container crane behaviors.

On the basis of the above results, I have proposed an earthquake resistant design method for container cranes to prevent legs lifting by combination of a simplified numerical analyses and the FEM analysis. This design method will alleviate the burden of design as well as being practical as a means of earthquake resistant design.

There still remain unclear elements for the lifting behaviors and the behaviors after lifting of legs in response to L2 seismic motion, although they have large possible effects on the crane and its foundation. For this reason I proposed earthquake resistant container cranes equipped with base seismic isolators as a means of preventing legs lifting. The model tests have confirmed that the base seismic isolators are sufficiently effective in preventing legs lifting.

This study analyzed behaviors of cranes during strong earthquakes. On the basis of the result of analyses, I proposed a procedure for earthquake resistant design of container cranes. The study also verified the effect of base isolators and reflected it in proposed safe and economic structure of container cranes. I hope that the results of this study will be incorporated in design standards and will thus contribute to improvement of earthquake resistance of container terminals. Then this study will mean very much in improvement of social infrastructure.