Abstract of Dissertation

Prediction of Bridge Vibration Incorporating Dynamic Interaction with High-speed Trains and its Comparison with Measurement

（高速列車との動的相互作用を考慮した橋梁振動解析と実測）

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High-speed railway technology has developed in line with Japanese social and economic changes and has seen rising speeds, cost savings, and safety, as well as falling environmental impact. However many of high-speed railway bridges were constructed 40 years ago and they have experienced increasingly intensive service load effects due to increased train speed and increased service frequency. Higher train velocities result in stronger dynamic interaction between trains and bridge structures. For the further increase of train speed, accumulated number of train passage may lead to fatigue or other damage problems. It is important to investigate the dynamic behavior of railway bridges thoroughly.

In this dissertation, the dynamic behavior of railway bridges is investigated through field measurement as well as numerical simulation, with an emphasis on the dynamic interaction between high-speed trains and bridge structures. The research has developed a universal numerical scheme of train-bridge interaction system using commercial software. The system is verified by measurement to be effective, resulting in the realization of the dynamic analysis and damage investigation.

For the experimental approach, this dissertation carried on field measurement of train-induced vibration of Shinkansen RC viaducts, using the ordinary velocimeters and accelerometers. Totally six adjoining viaducts were measured at the same time for comparison. The viaducts were excited in three directions, with almost the same vibration magnitude. The frequencies of train-induced vibrations are mainly dependent on the train speed, varying linearly with increasing speed. It is also shown that the higher frequency peaks of the train-induced vibrations are integer multiples of the first peak, owing to the periodic nature of the loading from the train wheels. Comparison of the RMS velocity of train-induced vibration showed large variations existed among the different viaducts. Even for the same train passage, the dynamic response of each viaduct was still very different. The response result was filtered within the interval of the first peck frequency by band-pass filtering. The comparison of the results still shows that the RMS velocity curves do not change after filtering in all directions. The variations among viaducts still exist in the low frequency vibration, implying the variations are caused by the fundamental difference of the viaducts. The track irregularity, the boundary condition and the soil and foundation conditions are speculated as the possible reasons which may cause the response variations.

For the simulation approach, a new numerical vibration prediction scheme of train-bridge interaction system using commercial software is developed. This versatile scheme is utilized

to treat the moving train and bridge as two separate systems, which interact with each other through the contact forces. One key step herein is the discretization of the second-order equations of motion for the trains using Newmark's finite difference scheme. By solving the contact forces from train equations, one can treat them as external forces on the bridge, which can then be solved using conventional finite element procedures. Since all the analysis procedures are using the general finite element software ABAQUS and the numerical software MATLAB, this approach could be expected to be used widely compared to some specific software from previous researches.

The capability and reliability of the proposed scheme is demonstrated in the study of dynamic characteristics problems encountered in the field measurement of the RC viaducts and steel bridge. A detailed numerical simulation model of the RC viaduct of Shinkansen railway has been established first by the scheme described above. The comparisons of time-history and frequency results show quite good similarities. This has provided the basis of the accuracy of the FEM model and the comparability with the real structures. The train speed is undoubtedly one of important factors which influence the response of the viaducts. The simulation results reveal that the RMS values of the structure responses increase with the train speed. The majority of the viaducts' vibration is in the low frequency range. At last various influence factors mentioned above which may influence the structure responses are analyzed. The track irregularity is proved to have a great influence on the lateral responses of structure. The continuous rail above the superstructure plays an important role of interaction effect between the adjoining viaducts, especially in the longitudinal direction. Most possibly, the soil and foundation status is speculated as the main reason to cause the variation phenomena observed in the measurement. The results reveal that the change of the soil stiffness has a great influence on the dynamic responses of the structure, which is much greater than previous two factors.

At a railway steel box girder bridge, damage was observed on the web of a main girder at the bottom end of a welded vertical stiffener. Finally the numerical scheme is utilized to investigate the dynamic property of this bridge. The relationship between local stress, local vibration and train speeds are investigated before and after retrofit. A sophisticated three dimensional FEM model is constituted first. The analysis results reveal that the majority of the vibration in the section is the high frequency, i.e., the local vibration in the section. The local vibration of the lower flange causes the local stress on the web of a main girder at the bottom end of a welded vertical stiffener where damages occurred. It is found that the vibration shapes before retrofit, which the web of a main girder at the bottom end of a welded vertical stiffener and the center of a lower flange make a supporting point and loop respectively, causes local stress. At last the dynamic performance of the steel bridge under the high train speed is predicted using the numerical model. When the integer multiples of basic train-induced frequency come close to the natural frequencies of local vibration at the lower flange, the magnitude of the vibration at the lower flange is amplified. When a train runs at high speed, the vibration at the lower flange does not grow in proportion to train speed. The vibration is amplified only when excited frequency by train comes close to the natural frequencies of local vibration of the lower flange. The discrepancy between the simulated impact factor and the one defined in the current design code implies that the approximation only using the first mode is a method to express the base area of the resonance peak and does not easily attain resonance within the high frequency components. Thus it is not a method to adequately express the resonance peak, especially for the high train speed cases. The influence of high modes should be considered in the design.

In summary, this dissertation proposes and realizes a versatile numerical scheme of train-bridge interaction system. The system is experimentally verified to be effective for dynamic analysis and damage investigation. Successful completion of this research indicates this approach is expected to provide not only an accurate simulation tool for train-induced vibration, but also instructive information for the design and retrofit of railway structures.