論文の内容の要旨

Abstract of Dissertation

Risk Assessment and Fatigue Life Prediction of RC Deck by Utilizing Survival Analysis and Full Scale Numerical Simulation

（生存時間解析とフルスケール数値解析を用いたRC床版のリスク評価と疲労寿命解析）

房 捷

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Large numbers of bridges were constructed during the periods of high economic growth in Japan. Nowadays, performance degradation have been widely found in reinforced concrete (RC) bridge deck slabs after almost fifty years of usage. In order to maintain these structures and ensure safety, a rational bridge deck slab maintenance system are need. Not only the overall deterioration feature, but also detailed deterioration process and mechanism is essential. As a first step, the Ministry of Land, Infrastructure, Transportation and Tourism (MLIT) announced an inspection system on 1 July 2014, which offers an opportunity for statistical analysis. A method called survival analysis has been used to analyze the bridge inspection data and the fundamental idea comes from medicine (Yamazaki and Ishida, 2015). On the other hand, the study of deterioration process and simulation for individual bridge also carried out at same time. The fatigue loading test under wheel load were conducted by Matsui sensei (Maeda and Matsui, 1984). Then in order to quantify the mechanism of the fatigue failure, instead of the two dimensional beam model, the three-dimensional fatigue simulation of RC slabs under traveling wheel load has been developed (Maekawa et al, 2006).

But still there were some problem exists in the previous study. For survival analysis, part of the results remained ambiguous and inconsistency results have been found in univariate and multivariate analysis. Therefore, appropriate data processing should be conducted in order to clarify the deterioration characteristics of each area and distinguish between high risk areas and low risk areas. For numerical simulation, the fatigue analysis only applied the load on the middle of a simple RC slab plate. In the actual situation, as the loading position changes, the distance between the load and the girder also changes, and it will directly affect the fatigue life. Additionally, since the actual structure is more complicated, the size, shape and boundary condition is totally different comparing with simple plate, the strain and stress distribution, displacement and moment is also different. Therefore, full scale numerical simulation should be used to get more accurate result. Additionally, based on the deterioration process, the limitation of survival analysis should be checked by comparing the result of both methods and the necessary information which can be used to improving the accuracy of inspection and survival analysis to be clarified.

Generally speaking, for the basic definition of survival analysis, one object can only have one survival time and survival state. However, according to the data processing from previous research, if one slab has been inspected multiple times, the continuous inspection record was treated as several independent data which violates the basic law. Therefore, data processing, including data cleaning and data selection should be appropriately conducted. In this research, each continuous observation of individual object was first treated as a datum, and pre-survival time was calculated. Then amount these data, one pre-survival time was selected as the true survival time. Moreover, univariate and multivariate inconsistencies caused by high correlation between variables are also modified by reducing the correlation of each variables to 0.5.

By conducting data processing and reanalyzing, the deterioration characteristics of different regions were clarified. Reduplicative dynamic traffic load was a major reason for the deterioration of bridge deck slabs in the Tokyo region. Correspondingly, thicker slabs had much greater loading capacity; therefore, a decreased hazard ratio was evident. Existence of water also shows some effects. Water flow is faster for slabs with greater slopes; thus, the hazard ratio tends to be smaller. For East Japan, the traffic volume is not a main deterioration reason since the traffic volume and hazard ratio is relatively small. Through the analysis, the result shows high deterioration risks in the severe winter environment region, including rainy and snowy weather, low temperature, less sunshine hour. Additionally, during the extended snow melting process, the water with a lot of chloride ions penetrates into cracks and accelerates the deterioration process. Rebar is

corroded and slab is seriously damaged unless there is appropriate protection and repair work. Using geographical coordinate information, risk scores and environment hazard map were made; distinctions between high-risk and low-risk areas were clearly shown. Especially in the mountainous area of Yamagata Prefecture, combine with the large amount usage of de-icing salt, the deterioration rate is relatively high.

One of the biggest advantages of survival analysis is grasping of the overall situation of the data. However, it cannot give any further prediction. In order to obtain the service life of each individual bridge, numerical simulation is used. According to the actual bridge design drawing, a complete full span finite element model with a length of 30 meters and width of 11 meters has been created. But large model which contained large amount of solid element will consume a lot of computation time. In order to speed up the calculation process, part of the solid elements were retained, and the remaining part was replaced by beam elements.

The result shows that the beam-solid hybrid full scale model can successfully analyze the fatigue life of the RC deck. However, full scale model and simple plate model show inconsistent results under dry and wet condition because of the different boundary condition. Therefore the usage of full scale model would be more previse. Next, In order to check different deterioration process and mechanism of full scale numerical model, the displacement decreasing trend, the maximum principle strain distribution, horizontal crack generation time and condition are compared between full scale numerical model. Under dry case, the fatigue cycle is greatly increased if the slab thickness was increased. However, under wet case, even though the thickness of the slab has increased a lot, the increasing in fatigue life is very limited. Additionally, in the case of the same thickness of the slab, the fatigue life in a dry and wet case are significantly different. These results are also consistent with the survival analysis results. According to the maximum principle strain distribution, it can be seen that the deterioration of slab under dry case thought a relative long time period. Since the damage is shown in the surface area, the current inspection can easily detect it and the survival analysis can considered this type of deterioration. However, for wet case, comparing with top surface, the maximum principle strain in the bottom surface showed a delayed trend. According to the road bridge deck maintenance management manual, it is said that the horizontal crack are generated after the acceleration period, which is the late stage of the deterioration. But base on the simulation result, the horizontal crack happened at the initial deterioration through a very short period. It is necessary to carefully consider the acceleration of deterioration due to horizontal cracks. Moreover, current inspection can not or underestimate the deterioration

under wet case. Then, by comparing with the result of different distance wheel load and girder, it can be found that when the loading is far from girder, the vibration amplitude is larger, higher water pressure is generated and fatigue failure can be reached faster. Finally, by comparing with single loading, deflection decreasing of actual load are accelerated. Therefore, by considering the actual loading position, the simulation can be more closed to the actual situation.

Future research directions will be focus on improving the simulation accuracy by considering the stagnant water location and the complex deterioration include ASR, frost damage, chloride attack, etc. Additionally, in order to avoid horizontal crack and early stage punching shear failure, the waterproof should be functional in all time period. GPR system should be induced to check inside condition of slab. And the bottom surface crack condition should be combine with the top and inside condition of slab in order to increase the accuracy of survival analysis.