【様式４】

“Technical Research and Development for Road Policy Quality Improvement”
Study Summary

No.	Title	Principal Researcher
No.25-4	Development of design verification method based on the performance based design concept aiming at the coming revision of the specifications of highway bridges: focusing on the substructures	Niigata University Associate Professor Yu Otake

This study is to propose design verification method based on the performance based design concept aiming at the coming revision of the specifications of highway bridges (SHWB), which is scheduled to take place in 2017. The main part of the development in this study will be implemented in the revised SHEB. The followings are the outcomes of this study:

- Based on the investigations on bridge substructure design in this country and the overseas, the impacts of the introduction of the partial factor design verification method as well as remained issues in the implementation are reviewed and clarified.
- It is expected that in order to truly realize the performance based design in SHWB, the accuracy of predictions for the displacement and the deformation performance of the structure should be improved. The estimation of soil parameters concerning the deformation characteristics of soil thus becomes the key issue in this context. Considerably large soil investigation databased accumulated in PWRI concerning the bridge construction all over Japan has been statistically analyzed, which eventually became a proposal of new estimation equations for these parameters. The accuracy of the estimation has been improved considerably from the present estimation equations in the SHWB.
- The method to determine the resistance factor for the cases that are unique in the substructures have been developed.
- A manual with several examples are drafted for practical design engineers to carry out the reliability based design by themselves.

1. Backgrounds and Objects

This study is to propose design verification method based on the performance based design concept aiming at the coming revision of the specifications of highway bridges (SHWB), which is scheduled to take place in 2017.

2. Activities in Research Period

The followings are the outcomes of this study:

- Based on the investigations on bridge substructure design in this country and the overseas, the impacts of the introduction of the partial factor design verification method as well as remained issues in the implementation are reviewed and clarified.
- It is expected that in order to truly realize the performance based design in SHWB, the accuracy of predictions for the displacement and the deformation performance of the structure should be improved. The estimation of soil parameters concerning the deformation characteristics of soil thus becomes the key issue in this context. Considerably large soil investigation databased accumulated in PWRI concerning the bridge construction all over Japan has been statistically analyzed, which eventually became a proposal of new estimation equations for these parameters. The accuracy of the estimation has been improved considerably from the present estimation

equations in the SHWB.

- The method to determine the resistance factor for the cases that are unique in the substructures have been developed.
- A manual with several examples are drafted for practical design engineers to carry out the reliability based design by themselves.

3. Study Results

3.1 Recognition of the impacts of LRFD and issues to solve based on the investigations

In the first year of this study period, we have invited Dr. John Kulicki and Mr. Tony Allen for the US. Dr. Kulicki is a very well-known bridge engineer who took key role when AASHTO specifications for highway bridges are revised from the WSD (working stress design) to LRFD in 1996. Mr. Allen works for DOT of Washington state, and only geotechnical engineer in the current drafting committee of AASHTO SHB. They both have published quite number of documents concerning LRFD of AASHTO SHB. They had intensive discussions with the code writers at PWRI, made several presentations in front of selected bridge engineers, and attended and made presentations at conferences and symposiums while they are in Japan in fall of 2013.

From Dr. Kulicki, we have learnt the following points:

1) The total amount of resources put to the bridge constructions have not changed significantly before and after the introduction of LRFD. However, the allocation of the resources among the bridges as well as the members have been optimized.
2) By LRFD, the AASHTO engineers have gained a quantitative scale for the safety of bridges. Based on this scale, they can now control the level of the safety of the bridges. One of the outcome of this gaining the quantitative scale is the development of LRFR (load and resistance factor rating), which is used to evaluate the performance of the existing bridges for repair and maintenance purpose.

From Mr. Allen, we have leant a lot of issues we face when we do code calibration to determine the partial factors. The method employed in the US are explained to us in a very detailed way. These information gave us a lot of insights for our own code calibration work.

We also made group interviews to the experienced bridge engineers in Japan to ask for issues that need to be improved in realizing really the performance based design. One of the main issues highlighted at those occasions were estimation of soil parameters concerning deformation characteristics of soil.

3.2 Development of estimation methods for soil stiffness coefficient E and the horizontal subgrade reaction coefficient k_H

In the bridge foundation design, the displacement is calculated by elastic theory based on so called equivalent linear analysis. The most important parameter in this calculation is the soil stiffness coefficient E . E is defined as a gradient of a secant line of the axial stress difference and axial strain curve at a certain strain level. This strain level essentially should be fixed based on the strain level of the ground that is generated by the level of the foundation displacement required by the performance of the structure. However, the current estimation methods specified in SHWB ignores the strain level of the ground at which E is estimated. Furthermore, this strain level is different form an investigation method to another. In this study, strain level generated by each soil investigation method is theoretically analyzed. Based on these considerations, a very large database of soil investigation results that are collected by PWRI in the last 20 years have been statistically analyzed. Obtained E's are analyzed by knowing the strain level at which those values are measured. Through these analyses and mechanical considerations, a new estimation method of E for several different soil investigation methods are proposed together with the estimation error that are present in each method.

In the horizontally loaded piles verification, the subgrade reaction coefficient k_H is employed. Essential theory behind this calculation is the same as above, meaning that the elastic theory based on so called

equivalent linear analysis is used. In order to carry out this calculation accurately, it is necessary to set the equivalent elastic stiffness coefficient based on the level of strain generated by the level of displacement considered in the design verification. A method is proposed in this study which relate the representative strain level of the soil and the level of displacement of the foundation under the design verification. By this method, an appropriate k_H value can be set based on the displacement related performance requirement for the structure through E..

The accuracy of the prediction for the displacement of structures are quantified using E and kH obtained by this study. The reliability of the predictions are different for different soil investigations and testing methods. Bu knowing these information, a designer can chose an more appropriate method for the purpose.

The obtained results are going to be included in the revised SHWB, and the works are underway. Furthermore, the following two papers have already submitted to JSCE journal.

1) Otake, Y., T. Nanazawa, Y. Honjo, T. Kono and A. Tanabe, Improvement of deformation modulus estimation considering soil investigation type and strain level, submitted in Jury 2016 to JSCE journal.
2) Otake, Y., T. Nanazawa, Y. Honjo, T. Kono and A. Tanabe, Improvement of subgrade reaction estimation considering deformation level and strain level, submitted in Jury 2016 to JSCE journal.

3.3 Determination of the resistance factors based on the reliability design method for problems that are particular to the substructures.

The substructures have some particular problems concerning the determination of the resistance factors by the reliability design method such as taking into account the quality and the quantity of the soil investigation methods and number of loading tests. Methods for the determination are not really established. The following methods are developed:

- Based on pile loading test database for a pile construction method that the resistance factors are fixed already, by randomly sampling a limited number of samples from the database to determine the resistance factors, the necessary pile loading test number that can practically get the same factors are investigated. The method is a kind of Bootstrap method.
- The procedure to carry out reliability analysis by Monte Carlo simulation (MCS) is presented together with several examples. A procedure to determine the partial factors based on this results are also explained.
- A method to renew the resistance factor based on the loading test done at a site is proposed in the framework of Bayesian statistical method.

3.4 A manual and examples for reliability analysis

A manual with examples which explains, step by step, how to carry out reliability analysis is produced. It is produced based on the fact that it is possible for designers to carry out a reliability analysis themselves to verify the performance of a structure. For this purpose, the statistical data that are used in the code calibration will be made in public after the revision of SHWB. The examples are pile foundation and shallow foundation of a bridge pile.

4. Papers for Presentation

Honjo, Y. and T. Nanazawa (2014): Process and evaluation of AASHTO LRFD highway bridge specifications, Kyouryou to Kiso (Bridges and Foundations), Vol.48, No.12, pp.26-31.
Honjo, Y. (2015): Partial factor design method in bridges: trend in Europe and in North America (1), Doboku-seko (Civil construction). Vol.56, No.2 pp.117-120.
Honjo, Y. (2015): Partial factor design method in bridges: trend in Europe and in North America (2), Doboku-seko (Civil construction). Vol.56, No.3 pp.157-160.

5. Study Development and Future Issues

The following topics may be necessary to follow up this study.

- When SHWB is revised in 2017, it will be necessary to make the practical bridge foundation designers to understand the essence of the partial factor design method (or the reliability design method). Thus, it becomes necessary to provide manuals and more examples of the reliability design method as provided in this study.
- To promote the proposal made in this study for the estimation of the soil deformation coefficient and the subgrade reaction, it is important to publicize the contents in various ways. It is important to publish papers and research memorandums, as well as discuss with other researchers for the improvements
- The most of the development made in this study is for newly constructed structures. The concept need to be extended to the repair and the maintenance of the existing structures. LRFR (load and resistance factor rating) done in the North America may give some hints for this direction of study.
- Book are necessary to promote the reliability design method to practical engineers which contain many examples.

6. Contribution to Road Policy Quality Improvement

The main part of this study will be included in SHWB which will be revised in 2017. The estimation method of the soil deformation coefficient and the subgrade reaction coefficient proposed in this study would replace the traditional method used in SHWB for more than 40 years.

The performance requirements to ridges from the society have become more diverse and intensified. Not only the ultimate limit state but other serviceability limit states that concerns with the displacement and the deformation properties of the structure are requited. The proposal made in this study is an answer to these requirements. It goes without saying that this is only a small step toward this direction. But the direction is believed to be correct, and is a big change.

7. References, Websites, etc.

Not applicable for this study.