Extended Bridge Inspection Module of a Life-cycle Based Bridge Management System

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Abstract:

Bridge engineers presently have to face more challenges considering the rising number of natural disasters has been the major threat to worldwide infrastructures. Consequently, the bridge authorities also need more effective methods and useful tools for managing bridges. In order to help bridge engineers and authorities to plan, design, build and maintain comprehensively for the longer service life of structures, a prototype of a life-cycle based Bridge Management System (BMS) for bridge disaster prevention is developed by National Center for Research on Earthquake Engineering (NCREE) in Taiwan recently. In this paper, the developing framework of a life-cycle based bridge management system for disaster prevention, NCREE-BMS, is briefly introduced that can be employed to improve the efficiency and the quality of bridge inspection work, to evaluate the capacity of bridge disaster resilience and to ameliorate the exactitude of bridge information. The main purpose of this paper is to present the extended module which affiliated to NCREE-BMS provides the functionality of record bridge inspection data. The data framework of the extended module follows the latest bridge inspection codes as well. The extended bridge inspection module provides a more intuitive and user-friendly interface for field bridge inspection work, and also enhancing the feasibility of applying NCREE-BMS to more bridges.

Keywords: bridge management system, bridge inspection, bridge deterioration

1. BACKGROUND

Bridges are the most significant infrastructures in transportation systems which play a very important role in national development. In Taiwan, due to the unique geographic environment, bridges become the majority of transportation infrastructure and bridges structural safety is regarded as one of the most important public issues. Moreover, since the rising number of natural disasters has threaten the safety of infrastructures, bridge engineers nowadays have to enhance the mitigation of hazards with the increase of structure service period. On the other hand, the expectation of the public increasing structure service period also kicks up the motivations to enhance the mitigation of hazards for engineers and researchers. Thus, the thoughts of life cycle as new ideas come up and can help engineers to plan, design, build and maintain comprehensively for the longer service life of structures. It also knows that the correct record of bridge inspection work can help the engineers to know the update condition of bridge structure and be useful for structural safety evaluation and disaster preventions. The thoughts of life cycle is conductive to engineers' judgments in planning, designing, building and maintaining comprehensively for the longer service life of bridge structures. As a result, putting the thoughts of life-cycle into structural inspection and evaluation work is a creative idea and seems necessary. According to the report of The International Association for Bridge Maintenance and Safety (IABMAS) bridge management committee in 2012, varied management systems are increasingly used to support infrastructure managers' decision-making processes with respect to the infrastructure objects for which they are responsible. Moreover, it is suggested that the need for standardization in the field of bridge management be investigated to improve infrastructure management by reducing duplicate efforts in the integration of new functionality into management systems and by encouraging the development of ever better systems.

A research framework and a preliminary model system of a life-cycle based bridge management system (BMS) for disaster prevention is proposed by NCREE recently, the developing system, NCREE-BMS, is expected to be able to improve the efficiency and the quality of bridge inspection work, to evaluate the capacity of bridge disaster resilience and to ameliorate the exactitude of bridge information. The developing system has the distinguishing evaluation functions for the bridge resistance to earthquakes, floods, service loads and deteriorations by collecting field inspection data and taking the planning and design information of existing bridges into considerations. The time-variant curves of bridge structural resistance to hazards during the service time of structures were going to be built by applying expert system technologies to construct evaluation algorithms for bridge management accompanying with strategies for prevention of disasters. Moreover, modular aid tools and the mobile portable system were also expected to be developed according to the practice and convenience of field inspection works. This paper presents the extended bridge inspection module of NCREE-BMS; the purpose of developing the extended module is to ameliorate the visual inspection items of field bridge structures for the better evaluation of the serviceability condition. The data framework of the extended module follows the latest bridge inspection codes as well. The extended bridge inspection module provides a more intuitive and user-friendly interface for field bridge inspection work, and also enhancing the feasibility of applying NCREE-BMS to more bridges.

2. DEVELOPING FRAMEWORK OF NCREE-BMS

The life cycle of a bridge can be divided into four stages which are planning stage, designing stage, construction stage and maintenance stage, in general, the planning stage and the design stage are both around 2% of the total time period of structure service life; the construction stage is 5% of the total time period. Consequently, the maintenance stage is 90%, the most part of the total time period during structure life. That is to say, doing the maintenance work on infrastructures plays a very important role to make sure the structural safety performance and the service quality presented could satisfy the need of users. As for the bridge maintenance work, field inspection is the basic task of bridge management for evaluating the condition of bridges. The owner of bridges have come to know that in order to make good or right management decision, a proper predictive models have to be developed based on accurate data collected from field bridges. Consequently, efficiency of the management work is heavily dependent on bridge inspectors to record detailed information for all of the structural elements of bridges and evaluate bridge condition based on that record.

Although engineers and owners of bridges can benefit from up-to-date information of the capabilities of the most advanced of bridge inspection technologies which are expected to record the detailed and accurate structural conditions and to provide useful references for evaluations work. However, it will generally cause a lot of effort to gather the detailed information and will not be applicable for the regular inspection work for field bridges. As a result, doing a proper full and accurate enough inspection on field bridges is a challenge that engineers have to face the dilemma of whether to do the less effort on field work or to get the more structural information for evaluations which should provide the representative or significant results for the disaster prevention. This section briefly introduces the developing work and the research frame of NCREE-BMS project, the extended module which is repeatedly schemed for practical bridge inspection work will be presented in the next section.

Regarding to the development work of BMS, three main technical parts with cooperated functionalities have to be mentioned (Paul D. Thompson and Brian Kerr, 1998). The first part is the modularization function. The developed BMS differentiates three levels, i.e. network-level, project-level and element-level, in accordance with the different way of management and applications. Among three levels, the element-level is the basis for applications of other two levels, thus managing modularized elements of a bridge and created graphic elements will be the basic function of BMS.

The second functional part of BMS is the information database which will store with bridge inspection data. The principle of design of this part is the customization functions. And the system design frame of this part is called MVC standing for Model, View and Controller. The Microsoft ASP.NET MVC design frame can reduce the component coupling between each part of components in the system and raise system capability on extension flexibility. The tools used for the data processing are MySQL Database and CouchDB, which are able to substantiate the table-column object in the database with flexibility.

The third functional part of BMS is the module which will apply expert system algorithms to evaluate and rate the condition of structures. This part will accomplish the design and implementation of the visual interface interacting with expert knowledge, integration engine of expert algorithms, the analysis core of Neural-aided expert system, the graphic user interface of expert system operation, and the management of database for bridge inspection data and principles. To sum up, owing to structural evaluation of bridge deteriorations needs the knowledge of experts, however, the experts are not easily trained and educated. As for large amount of data from bridge inspection work, it is needed to develop an expert system which can simulate the thinking algorithms like experts to help engineers or owners to evaluate the condition of bridge in time before the disaster happened. In general, the algorithms embedded in the BMS have to be reviewed and modified according to the back-feed information from field observation of bridges. Besides, NCREE-BMS also focus on integrating extendable and modifiable modules to put the system developed into practical use.

The Figure 1 shows the research framework of developing NCREE-BMS, the input information of bridge management system can be divided into three parts, which are inspection record, bridge inventory and the descriptions of the related regulations. In the proposed framework, the evaluation and disaster prevention modules are embedded in the system. And the output of the system would provide the information regarding to the condition of bridges, priority sorting and the beneficial result to authorities for making the optimal decisions. Conventionally, bridge inspectors record the inspection information on papers with graphic remarks to describe the damage condition of bridges. In this research work, portable devices will be applied to integrate bridge drawings and structural model presenting technologies to achieve mobilizing purpose. The visual inspection information will be recorded directly in the system, which will help experts more easy to determine and judge the condition of damage for bridge structures.

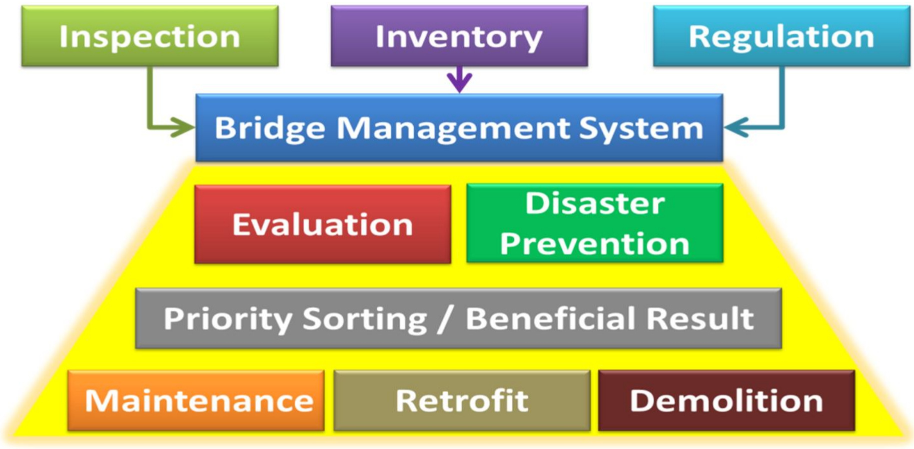

Figure 1. The research framework of developing NCREE-BMS

Performing a good bridge inspection can provide good quality of inspection report and data, which is the essential for evaluation. Also the bridge inspectors have to know their own the responsibilities of inspection work and understand the fundamental of bridge structures. It is needed to integrate the life-cycle thoughts with the predication models constructed for the evaluations of bridge deteriorations, and notice that the BMS should be used to collect the information regarding the bridge for its whole life time. In viewing this, it was proposed that the field inspection team at least includes two members, inspector and evaluator. The only task for the inspector is to collect the damage information and take field photos of bridges. And the evaluator should put the concern on completing the needed information for post-evaluation and building basic structural information of bridge components for inspectors use in advance. The recorded data or the exchangeable information between field inspector and field evaluator can be transferred via local wireless transmission network. By the mean of the division of labor for field inspection work, the improvement of the efficiency and the quality of bridge inspection is expected. The inspection process generally starts from reviewing the previous report and ends on finishing the documentation of bridge inspection findings. And the documentation of bridge inspection findings should include the inventory data, verbal descriptions, pictures or photos and the recommendations from inspectors. All the content mentioned above was put into the consideration while developing NCREE-BMS. Figure 2 indicates the service bus which can be flexibly built the connection between NCREE-BMS and other application functions for extended module use.

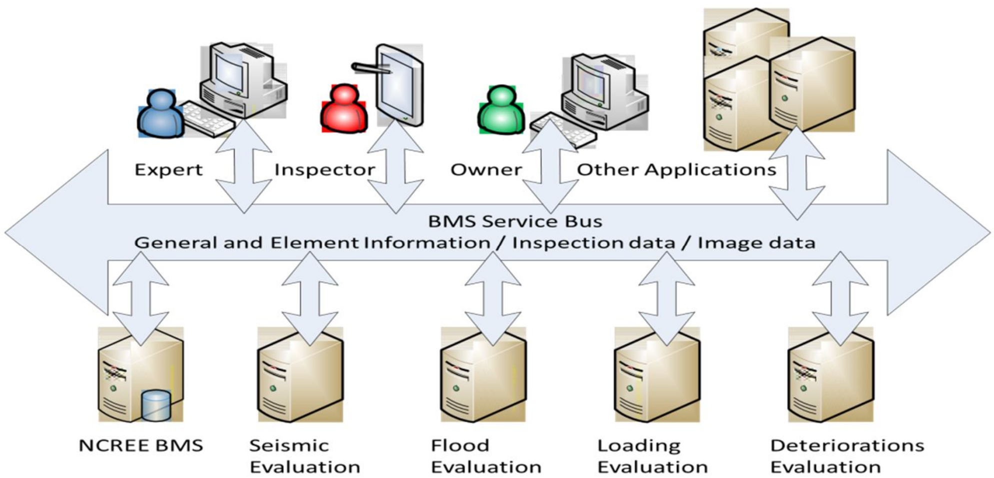

Figure 2. Proposed service bus for NCREE-BMS

3. EXTENDED MODULE FOR BRIDGE INSPECTION

As mentioned above, the quality of bridge inspection work is directly related to the reliability of bridge structural evaluation result. But due to the numerous of components and elements of bridge structures, it is impossible to conduct every detailed inspection for every bridge. It has to be clarified that the type of bridge inspection work primarily linked to BMS is the routine inspections, and the data from the other inspections, such as special inspections or non-damaged structural experiments results should be uploaded separately, and all results should be stored in the BMS database for the comprehensive evaluation. An extended module for bridge inspection is developed. The objective of inspection module is aiming to simplified field inspection work by extracting representative items, building graphic operating interface and using intuitive and visual tools, also aiming to let inspectors to provide more specific description and less evaluation to obtain objective inspection record.

The general information of inspected bridges is the first part data needed to be reviewed before conducting the visual inspection. And the second part needed data is bridge components rating information. The general information of a bridge includes bridge name, bridge location, date of inspection, design code used, load classification, date built, structural sections, structural length, number of spans, inspection records, and bridge structural descriptions available. And the bridge components rating information are traffic safety features, bridge deck conditions, load bearing components, abutments, piers/bents or pile bents, superstructure, substructure, channel and channel protection, the approach. It has to be noticed that the purpose of BMS is to manage information about bridges and to assure their long-term serviceability for public use under owner's budgetary constraints. An inspection database is the core part of a BMS, which is built up of records obtained from maintenance activities. The extended module was built in NCREE-BMS functionalities with needed considerations which are shown in Figure 3. Besides the inspection module, there are two distinguishing features of developing system can be noticed, one is the expert system module, and the other is the disaster warning module.

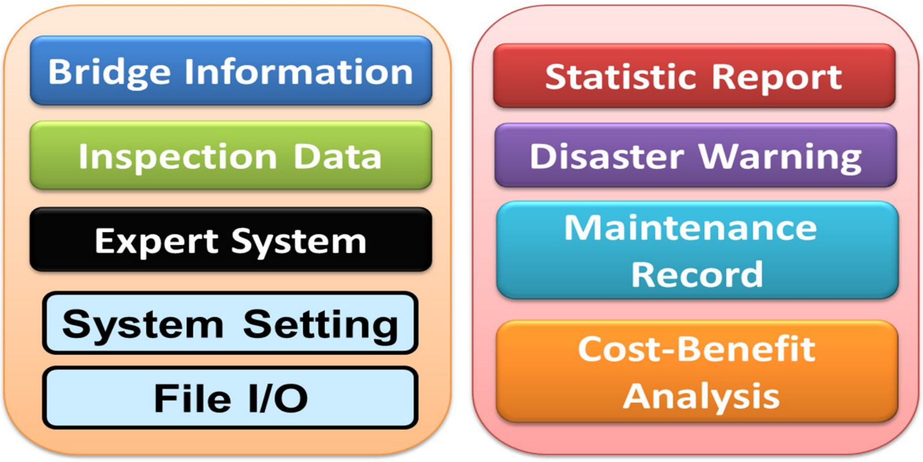

Figure 3. Developed functionalities of NCREE-BMS

In the bridge inspection module, the inspected elements of a bridge and the tree structure of inspection items which has to comply with inspection codes and verified by experienced engineers have to be defined. On the other hand, since the main purpose of bridge inspection work is to support the bridge management system to identify the needs of bridges for repairs, maintenance, preservation, reconstruction and replacement. The engineers or owners of bridges need such information to respond to those critical deficiencies warranting immediate attention and for the long-term management of these critical infrastructure assets to assure both public safety and proper performance.

Furthermore, the extended module was extraordinarily developed for the field inspection with more objectivity considerations. In general, a two-member team conducts the field bridge inspection work at the same time. One of team member collects the bridge damage information using camera taking photos, and the other one writes the description or check the table on the paper. In order to raise the objectivity of inspection result, thus we propose the thought that the division of labor for professional bridge inspection and evaluation as mentioned. The inspectors should focus on collecting field inspection data by using portable and useful tools to reduce the labor in the field and increase efficiency of inspection work. The evaluation can be conducted by remote system automatically, as long as the inspection record is good and the embedded evaluation module is good. The evaluation module, call expert system which should be developed and provide the result through experts' meeting conclusion or recommendations. So the system could help authorities of bridge management know the condition of bridge and make good decisions. The illustration of division of labor for professional bridge inspection work as shown in Figure 4.

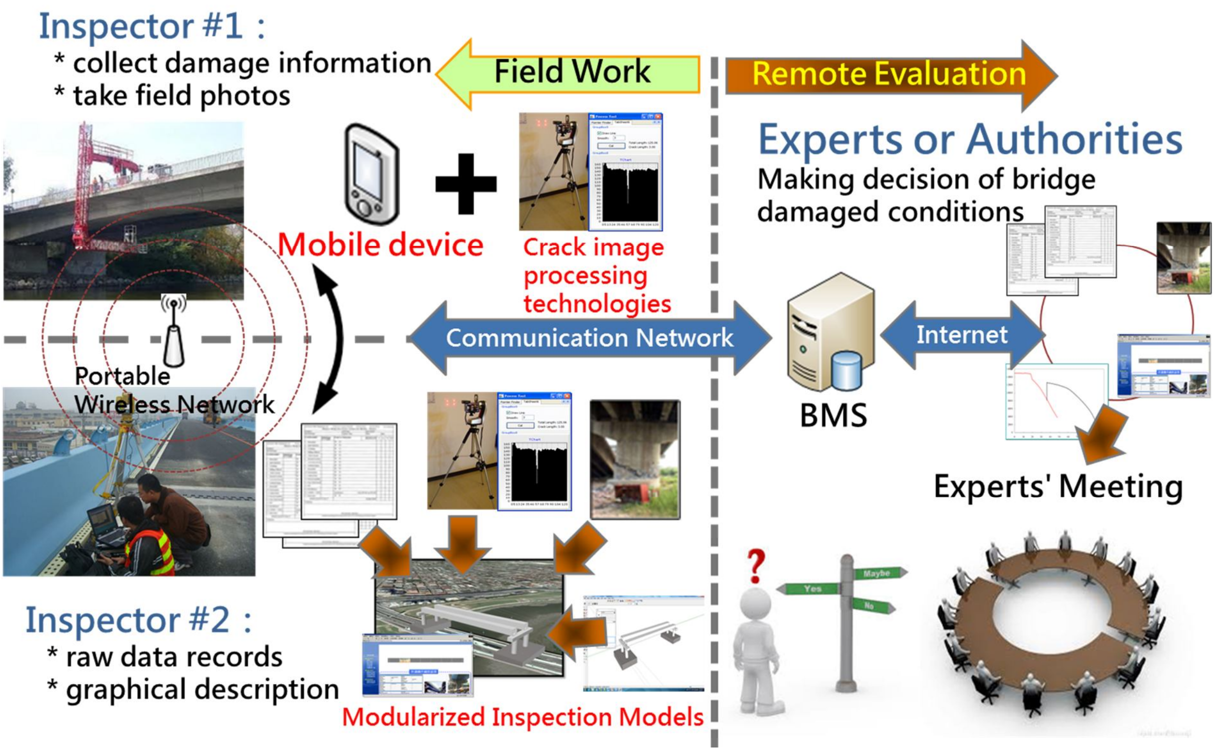

Figure 4. The illustration of division of labor for professional bridge inspection work

Next, the code compatible database of the extended bridge inspection module will be introduced. We know that it is very important to make sure the bridge inspection items and evaluation report should be consistent with related codes or regulations. In Taiwan, as for maintenance of highway bridges, there are specific codes of highway maintenance, and inspection and retrofit for steel and reinforced concrete bridges. The bridge inspection and evaluation method which is suggested in the codes and currently used in Taiwan are D.E.R.U rating methods. The degree, extent, and relevancy using a one to four rating scheme, Degree is defined as the severity of the element defect under consideration. Extent is the extent to which the defect occurs over the area of the bridge element. Relevancy is the importance of the defect of the element on the serviceability and structural safety of the bridge. And the urgency of maintenance is also defined. Twenty one inspection items are asked to be inspected for a general highway bridge in the codes. Moreover, the related codes have provided an inspection form for bridge inspectors writing down the rating of each inspected items. And the inspectors have to check the related tables for recommended value of D, R and U according to the deterioration status, as shown in Figure 5 and Figure 6. Honestly speaking, while doing inspection at the field bridge, if the inspector does not use some electrical inspection tools, smart phone or tablet pc for example, to check and to fill the code tables is a complicated and not a continent work for an inspector.

As a result, the developing system creates the database completely according to the related regulations. There are three databases, we call data tree showed in Figure 7, referring to inspection data, structure items and evaluation items separately. The inspection item tree lists the items need to be inspected. The evaluation item tree lists the evaluation items which are related to the consideration. For example, when we conduct the seismic evaluation of a girder, we have to check the girder type, the number and other needed information as a grouping evaluation items. The structure item tree stores the information which indicates the bridge type. For a conventional reinforced concrete beam bridge, there are bridge pier, span information and the abutment with related structural items. All sub tables were also concluded in the database of the system. Thus, it is ensured that the inspection result through NCREE-BMS is consistent with code by using the system.

Item	Inspeciton Item	Item	Inspection Item
1	Approach embankment	12	Bridge Protection
2	Approach barrier	13	Pier foundation
3	Streamway	14	Pier / Cap beam
4	Approach safeguard	15	Bearing plate
5	Abutment foundation	16	Restrainers
6	Abutment	17	Expansion joint
7	Wing wall / Retaining wall	18	Girder
8	Pavement	19	Diaphragm
9	Drainage facilities	20	Slab
10	Curb / Sidewalk	21	Other
11	Guardrail		

D : Degree
E : Extent
R : Relevancy
U : Urgency

Rating	0	1	2	3	4
D	N.A.	Good	Fair	Poor	Severe
E	N.A.	< 10 % < 30% < 60% <			
R	N.A.	Minor	Small	Medium	High
U	N.A.	Routine	< 3 years	< 1year	Emergency

Figure 5. Rating method for visual inspection of bridge in Taiwan

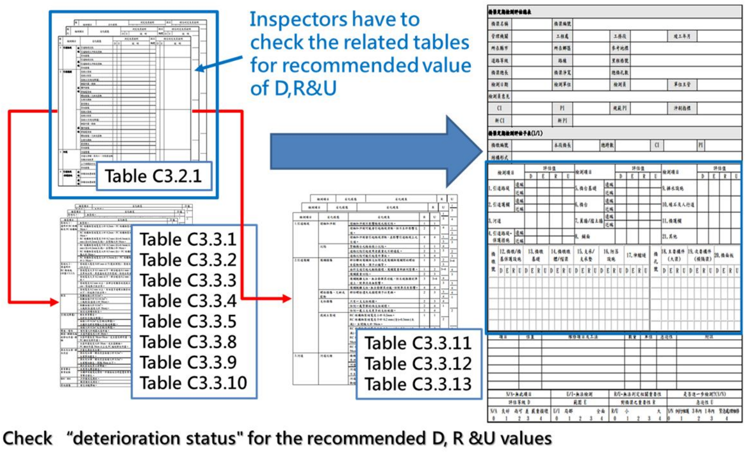

Figure 6. Sub-tables provided by related inspection codes for bridges in Taiwan

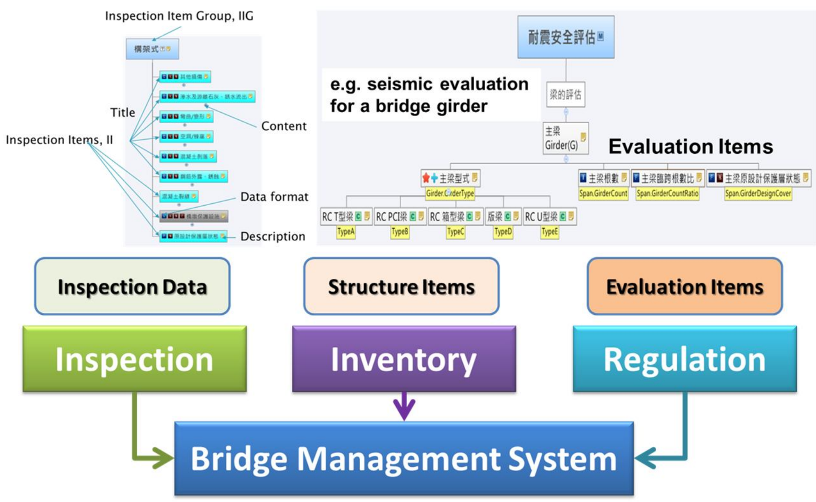

Figure 7. The database of the extended module for bridge inspection in NCREE-BMS

4. PILOT EXERCISE OF THE EXTENDED MODULE

Figure 8 displays the picture of the first three steps of the extended inspection module in NCREE-BMS. The inspector just has to pick the items listed and click to add an inspection record, pick the inspected defect, the deterioration status. And the extended module will automatically check the corresponding values of D, E, R and U out. The inspections data are completely recorded in the system and will automatically generate the inspection report draft for inspectors' review. In addition, with the help of the engineering consultant companies, a few pilot exercise of the extended module are conducted in field bridges as shown in Figure 9. And Figure 10 displays an inspection report draft of a pilot exercise bridge.

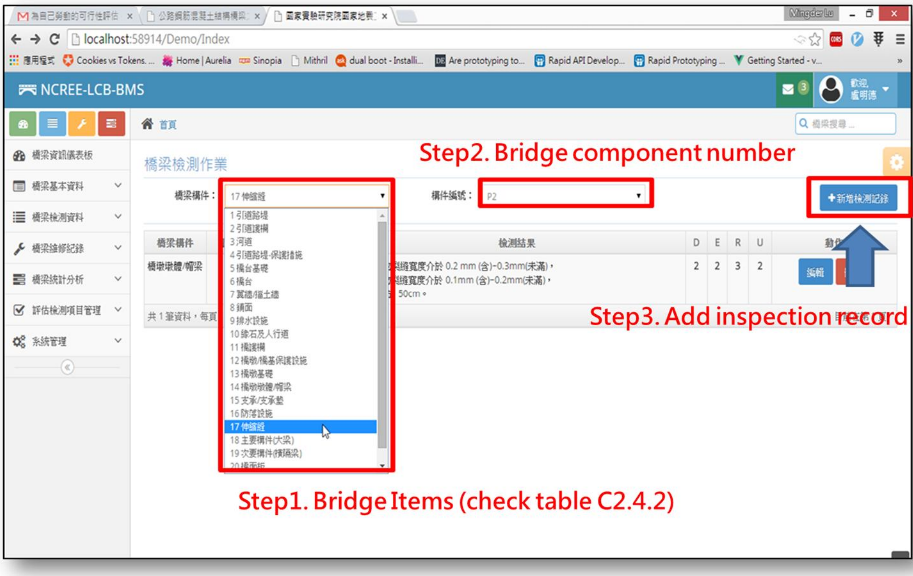

Figure 8. The picture of the first three steps of the extended inspection module

Figure 9. Pilot exercise of the developed inspection module in field bridges

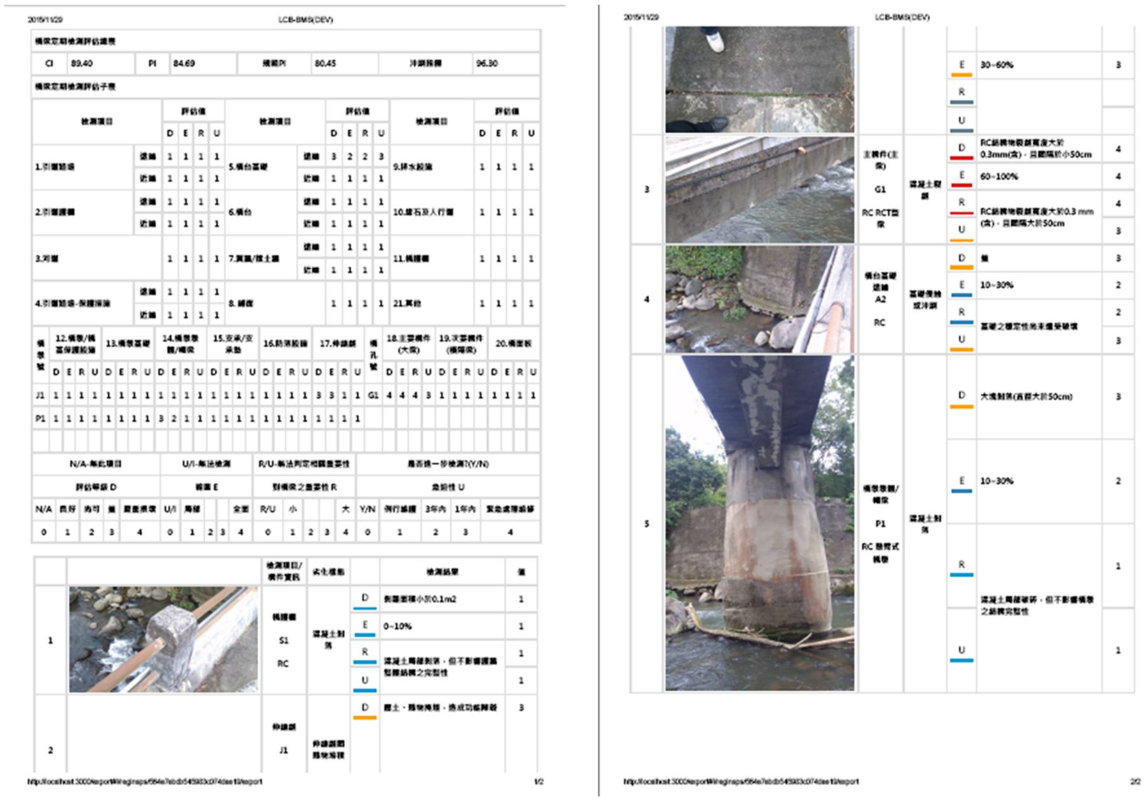

Figure 10. An inspection report draft of pilot exercises

5. SUMMARY AND REMARKS

In this paper, the developing framework of a life-cycle based bridge management system for bridge inspection and evaluation is introduced. NCREE-BMS is expected to be employed to improve the efficiency and the quality of bridge inspection work, to evaluate the capacity of bridge disaster resilience and to ameliorate the exactitude of bridge information with code consistent result. The developing system will provide the functions evaluating the trend of changes in structural resistance required by the bridge authorities and engineers for bridge management and disaster prevention. It also indicates that the purpose of the extended module is to ameliorate the visual inspection items of field bridge structures for the better evaluation of the serviceability condition. The most important and continued part of the developed work is to put the system in use, which can feed practical suggestions back and improve the system in the future.

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REFERENCES

Mirzaei, Z., Adey, B.T., Klatter, L. and Kong, J.S. (2012), The IABMAS Bridge Management Committee Overview of Existing Bridge Management Systems, *Proceedings of the IAMBAS 2012.*

Paul D., Thompson and Brian Kerr (1998), A New Bridge Management System for Ontario, ITX Stanley Ltd., Canada.