Proposed Maintenance Strategies for Highway Concrete Bridges in Vietnam

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Abstract: This paper reports on the investigation conducted on the existing bridges in Vietnam. The evaluation approach included visual inspections and non-destructive tests of concrete structures, personal interviews of site engineers in the field, and reviews of available publications from public media and literature. The diagnostic confirmed that the concrete was of low quality and showed many shortcomings such as failure, damage, local defects and premature aging. A series of diversified maintenance strategies is proposed to focus on both tactical and strategic levels. It is necessary to rectify current problems of concrete structures, to prevent the such collapse in future, and to enhance physical and serviceable conditions of the existing bridges in Vietnam.

Keywords: Defects, Bridges, Maintenance, Concrete, Vietnam

1. INTRODUCTION

Recently, the deterioration of reinforced concrete has become a major problem for the society resulting substantial costs, time and resources associated with repairing and replacing all of these deficient structures. Various research projects have investigated this problem and its negative impacts for existing structures. However, there have been few reports until now that can identify details of concrete deterioration in both structural ability and functionality. Reinforced concrete has been widely used since several centuries for constructing various structures of buildings, bridges, tunnels, dams, etc., hence, it is difficulties to clearly assess the quality of concrete.

This paper deals with common problems of concrete structures in Vietnam and proposes maintenance solutions. Existing bridges are specifically selected as the majority of Vietnamese bridges were constructed either of reinforced concrete or pre-stressed concrete since late nineteenth century. The adopted method of inspection included literature reviews to identify prevailing problems of concrete structures, together with site inspections and selectively non-destructive tests to ascertain their validity. Personal interviews were additionally conducted with various local stakeholders (e.g. engineers, owners, users and workers) to further understand the present condition and maintenance activities of inspected concrete structures. Aim is to establish modern methods of protecting, repairing and replacing of deficient concrete structures to enable existing bridges in Vietnam to last longer with better serviceability at acceptable maintenance costs.

2. HISTORY OF REINFORCED CONCRETE BRIDGES IN VIETNAM

Reinforced concrete is generally agreed to be of French origin, though it is argued by English and American historians. However, it was definitely France from where reinforced concrete came to Vietnam in the 18th century. The country had trade relationship with France and later became French colony in the middle of the 18th century. In early days, materials needed for reinforced concrete (e.g. stone, sand and reinforcement) were all imported from France. Later from the late 19th century, these materials have been locally produced in Vietnam as the country have huge sources of sand, gravel, limestone and iron mines.

Existing bridges in Vietnam consists of nearly 6,000 bridges over more than 194km long contribute all over the country [1]. They, together with road/rail routes, connected to different areas in the country and to foreign countries for economical exchanges, territorial extensions, etc. The construction of bridges started in 1881 with the 1,726.2 km long Tran-Viet track running along coastline throughout the country. Several historical landmarks of bridges in Vietnam are described as the following.

1) Period of 1881-1930: One-span simple bridges were constructed with materials imported from France. French standards were used for designing and constructing the bridges.
2) Period of 1930 – 1954: Large multi-span bridges with concrete piles, foundation and piers were constructed. While reinforcement bars and cements were imported from France, local sand and gravel were used to reduce construction costs and delivery time. French standards were used for bridge maintenance and management.
3) Period 1954 – 1975: The country was divided due to wars and bridges served mostly for military purposes. U.S and Soviet-Union standards were used in South Vietnam and North Vietnam respectively. Reinforcement bars and cements were still imported from various developed countries around the world.
4) Period 1975 – present day: Demand in transportation system has dramatically increased with the country’s unification in 1975 and economic boom in the 1990s. And with this the number of bridges has significantly increased. Materials for reinforced concrete were locally produced, except for high-strength rebar, pre-stressed cables, etc. Bridge-related standards developed by local authorities are now implied in the whole country.

3. GENERAL CONDITION OF EXISTING BRIDGES IN VIETNAM

Existing bridges can be classified into two categories (a) roadway bridges serve for land transportation of vehicles, motorbikes, bicycles, etc., and (b) railway bridges use for trains only. Bridges are classified by the transport ministry of Vietnam in terms of their lengths, materials, construction time and load-carrying capacities as shown in Fig. 1 [1]. A high percentage of existing bridges is in poor physical condition and functionality, causing many dilemmas for their stakeholders and negatively influence on the development of the country. In general, existing bridges in Vietnam have a wide range of shapes, commissioning dates and were built by various local and foreign standards. Some have been subjected to the impact of wars, the adverse climate and poor maintenance [2]. Many temporary bridges built to serve for military purposes are still in service. They of course do not satisfy the present civilian traffic requirement and need to be replaced as soon as possible. Meanwhile, there is different in geographical requirements for the bridges scattered through mountains, deltas and coasts; and the climate, as the northern area has four seasons (spring, summer, autumn and winter) and the southern area only has rainy and dry seasons. An extreme increase in vehicles carried in terms of volumes and weights are adversely impacting on the bridge conditions [3]. There is an assumption that existing bridges categorized as “old” and “very old” are not adequate for modern traffic, especially those which were affected by the previous wars or built before 1954.

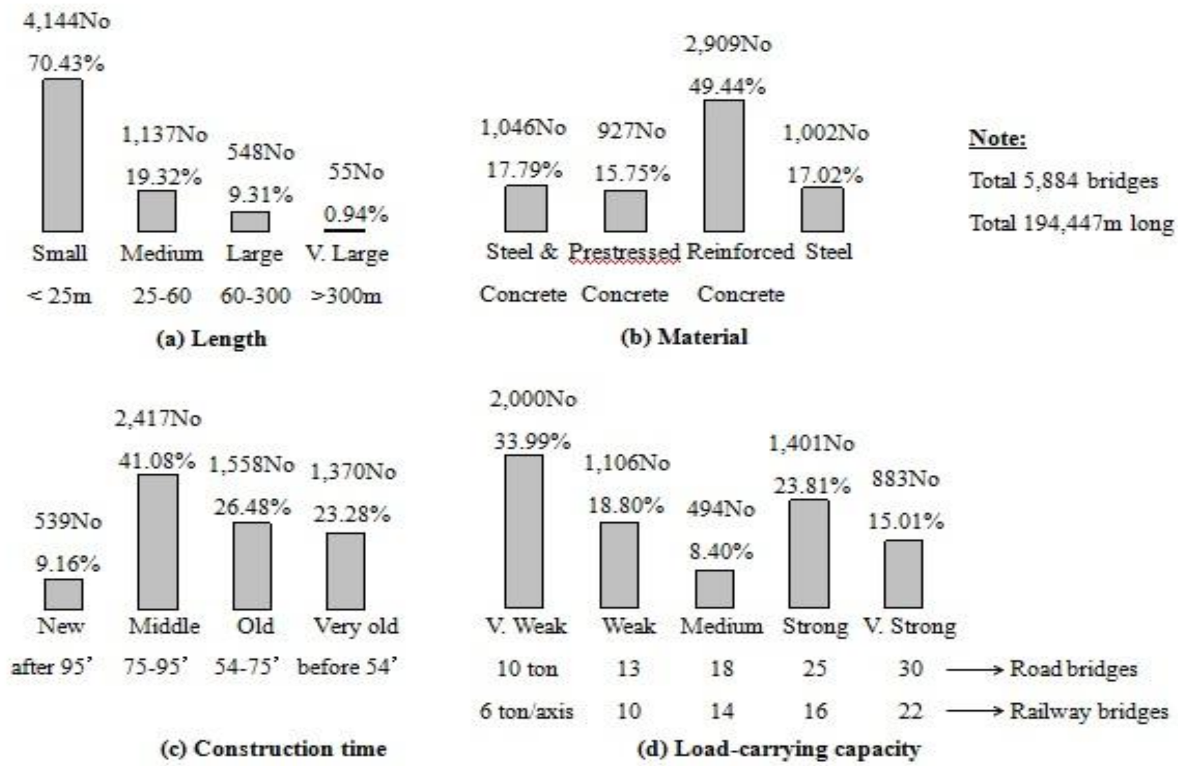


Figure 1. Classification of existing bridges in Vietnam

The statistical data shown in Fig. 1(a) confirms that existing bridges in Vietnam mostly fall under small/medium size categories, accounting for 70.43% and 19.32% of the total bridges. Concrete is the main material used in construction as steel bridges encompass only 17.02% of all bridges (Fig. 1(b)). Many weakened bridges are still in service although they can definitely not satisfy for modern traffic where there is demand for speed of 60-80 km/h and load-carrying capacity over 14 ton/axle/25 ton for trains/vehicles. Fig. 1(d) shows 33.99% and 18.80% bridges having load capacities between 6-10 ton/axle or 10-13 ton for trains and vehicles respectively to enable them running at speeds of 5-40 km/h only. 26.48% bridges fall under medium range with construction built in the period between 1954 and 1975 and 41.08% bridges were built between 1975 and 1995 (Fig. 1(c)).

4. COMMON PROBLEMS OF REINFORCED CONCRETE STRUCTURES IN VIETNAM

The history of reinforced concrete assimilation in Vietnam is perhaps cause to effect present problems. Due to external impacts of adverse climate, traffic vibration, extreme live-loads, etc., concrete structures which were designed for various imposed design and construction standards (either local-made or oversee) suffered durability problems. By the time, several problems occur in existing concrete bridges of Vietnam that may be serious as catastrophic and large cracks, or may be local defects of corrosion with spalling. Several common problems of concrete bridges in Vietnam can be identified through site inspection, non-destructive tests and personal interviews. They are illustrated according to their degree of seriousness and frequency of occurrence as follows.

4.1 Catastrophic failure

Structural catastrophe of existing bridges has been studied by many field researchers, including those residing in Vietnam. Hai et al. [4] considers the term ‘bridge failure’ as structural collapse for whole bridge or its key components that claim for lives and traffic interruptions. According to this definition, failure occurred occasionally for concrete bridges in Vietnam causing total collapse of the whole bridge or partly destruction of main structures. Many remaining structures of failed concrete bridges in Vietnam can still be observed today (Fig. 2). The cause of bridge failure is generally agreed among local engineers for unforeseeable impact of extreme-high loads and vibrations created by vehicle traffic, high-forced collisions and heavy flood. This impact imposes serious threats for concrete structures to be not always withstanding. Another cause is the fierce attack of missiles, bombs and explosions done throughout several liberation wars that Vietnam has experienced until 1975. Although this specific-country cause has been stated very much by local media, it is still not widely published yet.

Figure 2. Failure of existing concrete bridges

4.2 Chloride damage

Remarkable cracks and spalling with rust-water have appeared on the surface of concrete bridges in various locations (Fig. 3). The electrical half-self method that complies with Vietnamese standard TCVN 294:2003 (equivalent to ASTM C876) was employed to nondestructively identify chloride damage of existing concrete structures. Results shown in Table 1 indicate that rust appears seriously in the superstructures of almost all surveyed bridges, while rarely happens for substructure under water levels. The literature [5] that indicates the cause of such problem is salt that enters the concrete from outside after it hardens proves to be true for concrete bridges in Vietnam. In costal areas along over 3,000km length of Pacific Ocean, seasonal sea wind and waves dominate in summer. They bring salt particles that penetrate into concrete structures, together with a wide range of temperatures fluctuating from 6^{o}C to 39^{o}C and high relative humidity (80% average), cause corrosion of rebar and pre-stressed steel. Lack of proper surface protection is also claimed as a cause of corrosion as concrete in all the existing highway bridges has only fair-face finishing without paintings. The small thickness of the protective layers of concrete, varying from 15mm to 50mm only is unable to protect rebar from the impact of adverse climate. Therefore, corrosion occurs at almost all of the concrete bridges in Vietnam, within a relatively short service lifespan of 3-10 years.

Superstructure Upper-structure Bridge deck

Figure 3. Chloride damage of existing concrete bridges in Vietnam

Table 1. Current situation of corrosion and their main causes

Locations	Occurrences	Degrees of damage (rebar deduction rate)	Main causes
Upper-structures (from deck level upward)	Very frequent (100% bridges)	Light (maximum for 30% steel areas)	Adverse climate of high moisture, heated sunshine, salt, wind and
Superstructures (2m above water level)	Frequent (70% bridges)	Serious (maximum for 80% steel areas)	waves, dramatic change in temperatures, etc
Tide-zoned structures (up to 2m above water)	Sometimes (40% bridges)	Moderate (maximum for 50% steel areas)	Lack of protective coats for concrete surfaces
Substructures (under water level)	Rare (15% bridges)	Not happen (only few corrosion signals)	Thickness of concrete covers are only 15-50mm thick

4.3 Structural damage

Concrete structures are vulnerable to damage due to high variation in live-load stresses and vibrations. The damage of concrete shown in Fig. 4 as examples has been one of the major maintenance problems for existing bridges in Vietnam currently. Fatigue cracks generally occurring on transverse direction of superstructures (e.g. decks and girders) are common damage of concrete bridges. These cracks do not only decrease load-carrying capacity of bridges, but also allow active ions such as Cl^- and SO_2 contained in surrounding atmosphere to penetrate into concrete structures and cause subsequent occurrence of corrosion. The problem of concrete spalling and de-lamination have also confirmed through site inspection and personal interviews in Vietnam. They are found at various places such as deck bottoms where there is evidence of corrosion, substructures that are under the impact of waves and scouring, and upper-structures due to collision and friction. Under the adverse impact of cracks, spalling, de-lamination, etc., concrete layers become weakened and dropped off from main structures to cause subsequent damage to people and vehicles transporting underneath of existing bridges. Table 2 illustrates the current status of common concrete damage found in existing bridges in Vietnam and their possible main causes.

Figure 4. Damage of existing concrete bridges in Vietnam

Table 2. Typical concrete damage occurs on inspected bridges in Vietnam

Structural damage	Occurrences	Degrees	Main causes
Fatigue cracks	Frequent (70% bridges)	Serious	Traffic overloads in terms of weight and number of vehicles as well as frequently jams and congestions. Exceeded collisions due to large and high speed moving vehicles and vessels. Other causes of bombs and explosions, external impacts, construction mistakes, local defects, human invasions, and so on.
Concrete de-lamination	Sometimes (40% bridges)	Serious	
Concrete spalling	Frequent (70% bridges)	Moderate	
Dropping off of concrete	Sometimes (30% bridges)	Moderate	

4.4 Premature aging

Premature aging is a common problem in Vietnam. Hai et al., [4] indicates that most existing concrete bridges in Vietnam were built 10 to 50 years ago and were designed with a lifespan of 100 years. However, premature aging signs such as shown in Fig. 5 could be seen visually on almost all inspected bridges built before 1995. Mosses, funguses and shipworms were commonly observed at concrete surfaces, while erosion, swelling, decay, etc., occurred on load-carrying components of bridges. These have lead to a decrease on the physical condition and serviceability of existing bridges. Moreover, they speed up the process of developing failure mechanisms. Bridge lifespan therefore have to be shortened by less than 40 years of the expected design life [2]. In addition to the premature-aging problem, there are considerable number of concrete bridges (3.73% of the total number) having age over 50 or even 100 years are still in service. They are considered very old and not having the structural and functional abilities to serve modern traffic demands. Details of premature aging problem and its causes are shown in Table 3.

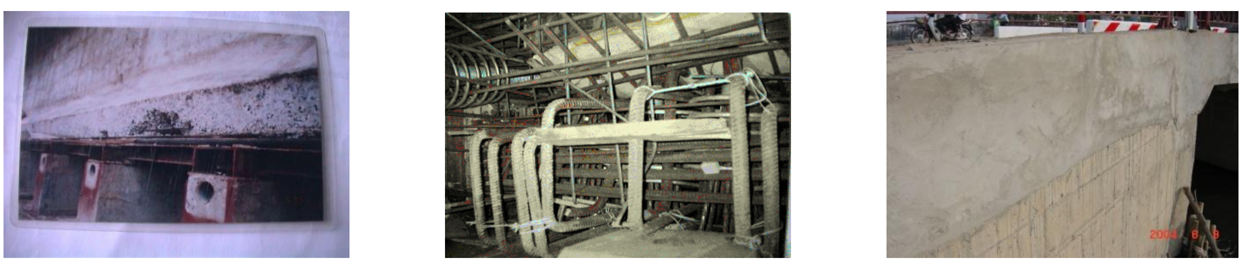
Figure 5. Evident of premature aging found on existing bridges in Vietnam

Table 3. Premature aging problems occurred on concrete bridges in Vietnam

Premature aging problems	Occurrences	Degrees	Main causes
Aging bridges with age 50 years upward	Sometimes (23% bridges)	Very serious (may collapse)	Adverse climates with high humidity, salt airs, heavy rains, etc Lack of proper maintenance to remove unexpected aliens from bridge surfaces Use unsuitable and not durable materials against weather attacks There are many old bridges in services Problem of fatigue, corrosion, scouring have not been quickly remedied
Signals of shipworms, mosses and funguses	Frequent (80% bridges)	Light (surfaces only)	
Occurrence of material cancers such as decays, erosions, de-lamination, spalling, etc	Frequent (70% bridges)	Moderate (penetrate lightly into superstructures)	

4.5 Construction and design defects

Defects that are due to construction mistakes or design miscalculations occur frequently on existing bridges in Vietnam. This fact is widely recognized by local engineers and authorities as many such incidents were recorded and published on public media. Dac et al., [6] mentioned design standards of Vietnam that are mostly modified from oversea standards prove not totally suitable for local condition. In addition, the miscalculation or misassumption of incompetent designers, can lead to complete failure of concrete structures after their completion. Typical defects caused by design mistakes are confirmed through personal interviews of field engineers as congested steel bars' arrangement or inaccurate layouts of reinforcement, thin protective layers, low-strength or poor weather-resistant concrete, and so on. Meanwhile, construction defects have been clearly identified by Hai et al., [4] as poor concreting in terms of quality, surface finishes, rebar layouts, etc. Site inspection has also recalled construction and design defects such as honeycombs, segregations, shrinkage and temperature cracks, poor connections and joints, and improper positioning. Several examples of these defects are shown in Fig. 6.



Concrete honeycomb　　Over-density of rebar　　Poor surface finish

Figure 6. Problems occur on bridges that originate from design and construction mistakes

5. FUNDAMENTAL MAINTENANCE STRATEGIES FOR HIGHWAY CONCRETE BRIDGES

Existing bridges in Vietnam are undoubtfully important in overall transportation network to contribute significantly into economic growth and social development of the country. However, concrete condition of these bridges has been generally agreed among field engineers to be in poor quality and surface appearance. The above analyzed problems decrease physical condition of bridges. Therefore, they must be eliminated as soon as possible in order to ensure bridges of expected quality and serviceability, and to smoothly serve for modern traffic. Any proposed maintenance technique needs not only a theoretical but also a practical interest. Here is an attempt to illustrate several maintenance strategies for overcoming current problems of concrete bridges in Vietnam.

The authors consider that a sole solution is not enough to totally eliminate all current problems of concrete bridges in Vietnam. Therefore, series of diversified proposals are concurrently made for specific concrete problems that aim mainly into their symptoms and root causes. Among six maintenance strategies proposed below, first three target the tectical level of site maintenance. Meanwhile, last three strategies propose strategical changes of current maintenance management practice of Vietnam. Details of proposed strategies are illustrated follows.

Table 4. Proposal of specific site maintenance for concrete bridges in Vietnam

	Scopes of site maintenance	Locations	Purposes
Preventive maintenance	Protective painting on surfaces of concrete structures (new or old)	Underneath of decks, slabs, girders, etc	Prevent chloride attack on reinforcement
	Cleaning on concrete surfaces, removing unexpected aliens	All bridge structures, specially for hidden components and locations	Prevent the occurrence of shipworms, mosses and funguses
	Routine and periodic visual inspections	All bridge structures, specially for hidden components and locations	Early detect defects or potential causes of defects
	Early involvement of maintenance agencies into design and construction stages	Designers' offices and construction sites	Help designers / contractors preventing current-encountered maintenance problems
	Strictly control vehicles in terms of their allowable weight and volume	Approach road at both sites of bridges	Prevent vehicle overloads and overuses
Essential maintenance	Replace for weakened and damaged concrete structures	All key components such as decks, slabs and girders	Eliminate catastrophic failures and serious damages
	Remove spalling and dropping off concrete and replace them by new concrete	Concrete surfaces where there is signals of corrosion, cancers, damages, etc	Eliminate or decrease chloride attacks on reinforcement
	Repair for concrete defects of cracks, honeycombs, erosions, etc	All bridge structures, specially for key components of bridges	Prevent existing defects further developing or reaching to ultimate levels
	Apply the priority method to select maintenance scope, basing on priority of required maintenance	Elements of bridges in specific and bridges of same networked routes in overall	Orient limited maintenance budget into necessary site works

5.1 Site maintenance

Even though reinforced concrete is a durable material, there are still many problems currently occurring on existing structures in Vietnam. Maintenance is necessary to delay the physical deterioration, eliminate current defects and prevent the occurrence of potential problems. However, annual budget provided can satisfy only about 30-50% actual demands creating dilemmas for maintenance agencies when encountering with concrete defects [7]. To overcome this difficulty, the authors propose certain essential and preventive maintenance strategies which if implemented require total costs within approved budgets and can significantly eliminate current defects and their potential causes (Table 4). The justification for essential maintenance is that if it is done on time it will eliminate current defects on concrete structures. The justification of preventive maintenance is to prevent potential problems by eliminating their potential causes early.

5.2 Defect monitoring

It is agreed that current defects of existing concrete bridges can not be instantly eliminated due to present limitation of annual budget and rigid maintenance procedure in Vietnam. Change of the system needs substantial time and resources. The current difficulty can be solved only if proposed preventive measure and essential maintenance is implemented to gradually remove existing problems and their potential causes. In addition, defect monitoring system should be created and applied in order to detect new defects, to record their progress, and to warn authorities the occurrence of existing defects. Corrective remedies therefore can be early carried out to eliminate defects and potential causes so new defects and their adverse impacts are minimized as much as possible.

The advanced defect monitoring system (V-DMS) simultaneously with the computerized database is currently under development by the authors for monitoring defects of existing concrete bridges in Vietnam [8]. Two matters are assigned for the V-DMS as (a) monitoring of bridge defects: cracks, spalling, fatigue, etc., (b) monitoring of external condition: traffic vibration, vehicle loads and volume, overall and local transpositions of whole bridges and specific components, etc. Several advanced techniques such as sensors, thermocouples, gauges, etc., that are suitable for local condition of Vietnam have been introduced into the proposed V-DMS to properly accomplish targeted aims. Furthermore, an inventory database is constructed to collect defect-monitoring data, to analyze gained results and to conclude status of defects for bridge authorities to make necessary corrective actions.

5.3 Establishment of inspection system

It is necessary to collect quantitative and objective information in inspections to grasp the soundness of existing bridges, to forecast subsequent deterioration, and to decide on the type and execution time of the preventive and corrective measures. Therefore, the type and the degree of the damage discovered in bridge inspections are recorded objectively and quantitatively by numeric information, figures, and photographs. Bridge condition and their defects obtained by inspections are continually monitored, and bridge histories, from inspection to repair, are preserved, accumulated and updated as a database.

The authors propose an inspection procedure for existing bridges consisting of consecutive steps from activity ① to ⑨ shown in Fig. 7 [9]. Definition of the inspection is not simple site inspection, but includes structural analysis to theoretically assess bridges in terms of their load-carrying capacity, reliability and behavior through several uncertain options. In addition, the load rating is the process to measure safe-load and ultimate-load carrying capacity as well as certain response characteristics of existing bridges. The site inspection that forms the core of the proposed system is compulsorily required to detect defects and their potential causes. Three types are proposed for superficial (patrol), principal (periodic) and special inspections (Fig.

8). A superficial inspection of bridge structures is performed daily throughout examinations of patrol teams in accordance with formal instruction. In the periodic inspection, the condition of bridges is determined through visual inspection, non-destructive tests and site measurement. Special inspection supplements for the patrol and periodic inspections and is performed as required following disasters or accidents or follow-up inspections after repairs.

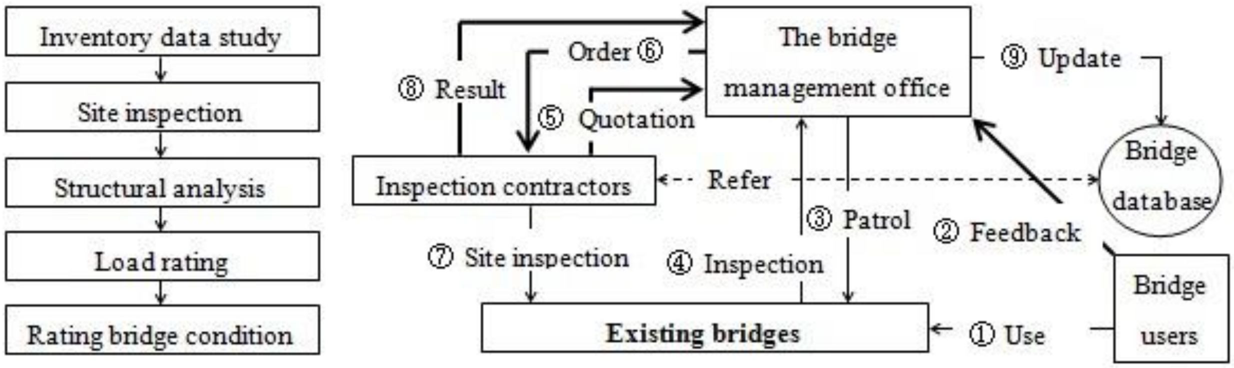


Figure 7. Inspection procedure for existing concrete bridges in Vietnam

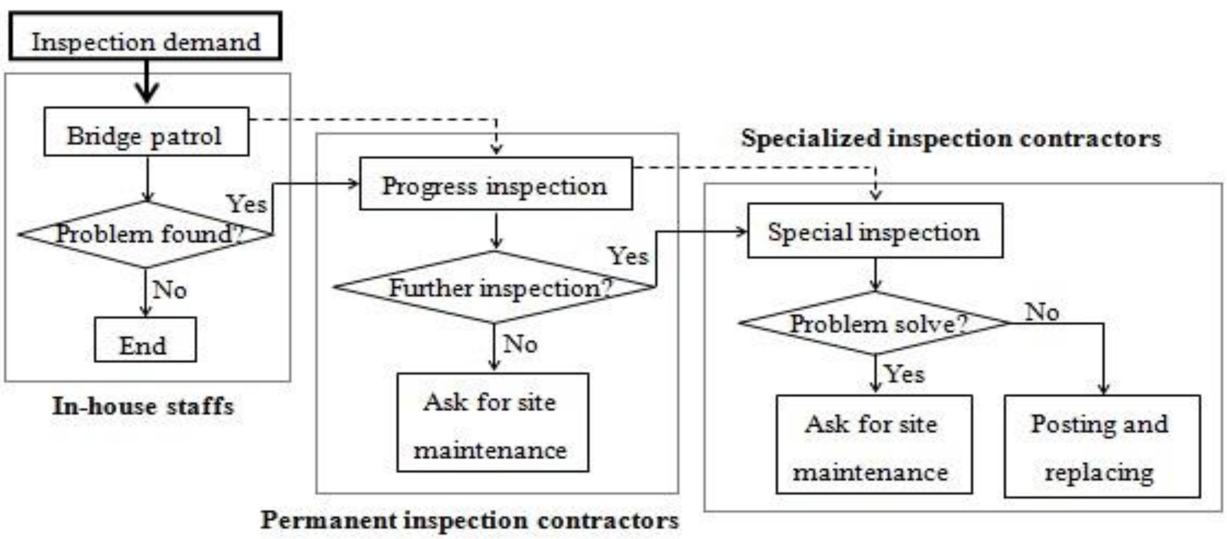


Figure 8. Categories of visual inspections for existing bridges

5.4 Appropriation of bridge standards

Due to historical condition, bridge-related standards of Vietnam that are written by local authorities have been compiled from standards of many foreign countries such as Soviet Union, U.S, France, and U.K. The current poor research infrastructure and high demand of new standards force bridge authorities applying foreign standards into local design and construction practices without testifying and modifying them. Thus, several foreign-copied clauses are not good for specific conditions of Vietnam. Besides, several purely local-made clauses that reflect either economical or social viewpoints seem not suitable for general practices of bridge design, construction and maintenance. There are plenty of inappropriate clauses of current bridge standards, but they are scattered in different archives or issues. Their modification deserves special studies by professional committees to broadly review standards, to propose alternatives, and to testify new proposals prior to actual applications. The authors carried out an intensive review of current bridge standards of Vietnam and found several inappropriate clauses as listed in Table 5.

Table 5. Examples of inappropriate clauses of current bridge standards in Vietnam

Inappropriate clauses	Originated by	Causes of inappropriate
Protective concrete layers are required for 15-30mm.	Compiled from Soviet Union standards.	In high-humid and salt-air condition of Vietnam, corrosion and crack quickly develop on surfaces where concrete cover is less than 50mm.
Safety factors are using in design for 1.5-2.0 times of actual imposed loads.	Compiled from Soviet Union standards.	Vehicle overloads and overuses are frequently two times greater than indicated maximum loads.
Used all imported materials from France in early time until 1954.	France imposed regulation for colonial country of Vietnam.	Many current concrete structures were decayed as they are not suitable for Vietnamese climate that very much differs with France climate.
Protective paintings must not be applied on concrete surfaces of bridges.	Local-made clause for cost deduction and easily visual inspection	Surface coatings acted as inhibitors to prevent corrosive attack from moisture, high salt-content air, and oxidizing chemicals are not available.
Maintenance agencies are not required to involve in bridge design and construction stages.	Local-made clause for separating between creation stage and operation stage.	Several problems are repeatedly happened on existing bridges as previous lessons of maintenance have not been learned by designers and contractors.
Practice of using low quality materials.	Locally-made bridge specification for low construction cost.	Low-quality materials are not durable enough to withstand adverse climate, high moisture condition, etc., and prematurely degrade physical condition.

5.5 Control during bridge creation stage

Currently, there are many defects originated during design and construction periods in the existing concrete bridges in Vietnam that have adverse and expensive impact. Bridge creation stage that includes design and construction need to be controlled in order to ensure defect-free completed bridges with maintainability characteristic. The practice that maintenance management agencies are not legally required involving into design and construction stages should be changed. If so, accumulative experience of maintenance institutions can be efficiently mobilized at early stage for eliminating repeated design and construction mistakes. On the other hand, a good quality assurance/control system is very important to assure quality of design, construction and maintenance for bridges should be created and applied in Vietnam. It helps to create a favorable working environment where intuitive decisions are minimized and formal procedures are respected among all stakeholders of bridges. If so, the occurrence of design and construction defects is unlikely while bridge-related data is properly managed and utilized.

5.6 Maintenance management system

Effective maintenance management systems for existing bridges have been implemented by many countries. Chase and Gaspar [10] mentioned the uses of the Pontis and the BRIDGIT at U.S. federal highway administration to provide comprehensive supports, to determine the optimum expenditures and to maintain a specified level of service for bridge population. Meanwhile the J-BMS is proposed for Yamaguchi-prefectural government in Japan to evaluate bridge performance and to estimate deterioration and remained service life. It is necessary to generate maintenance strategies in considering actual cost, budget availability and effect of maintenance [11]. In Vietnam, even paper-based maintenance management is currently used; however, several computerized systems are practically suggested for existing bridges. One of them is the BridgeMan of the British Parkman consultant is under consideration [6]. However, it limits to manage bridge inventory data only. The function for evaluation and prediction of physical condition and serviceability as well as actual expenditure and site maintenance are so far not available.

This research proposes a model of maintenance management system for existing bridges in Vietnam that consists of three modules for management, assessment and maintenance as shown in Fig. 9 [9]. The management module administrates physical conditions and serviceability as well as original and updated bridge-related data. The assessment module is considered as intermediate stage to change from office ideas to actual site-works. It gives an overview of bridge inventory data together with experts' opinions, knowledge, experience, etc., in order to suggest suitable maintenance management activities for bridges. The maintenance module involves in direct site-works with objectives to preserve and enhance bridge quality and serviceability against impacts of traffic, environment, elapsed time, etc. A computerized database is simultaneously constructed to store inventory data, to assess bridge physical and serviceable condition, and to output necessary information for proper maintenance management of existing bridges. Fig. 10 shows the organizational structure of the proposed database that required activities are consecutively carried out from ① to ⑥.

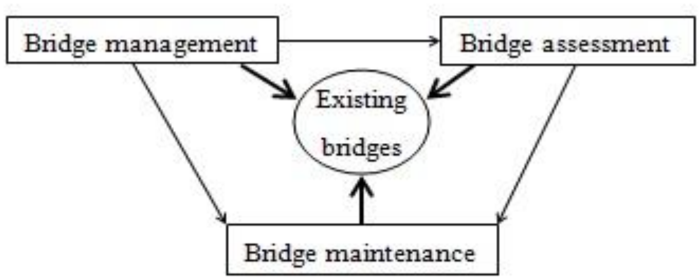


Figure 9. Proposal of maintenance management model for existing bridges in Vietnam

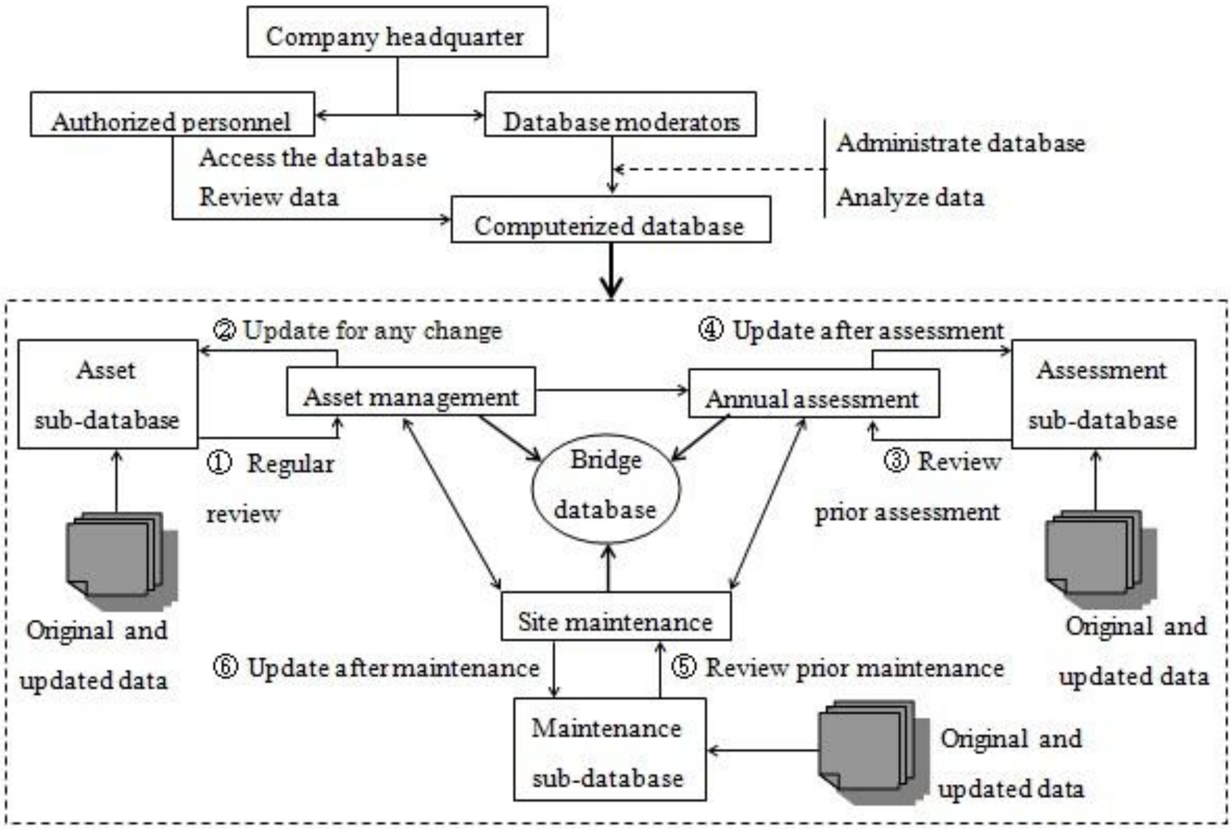


Fig. 10. Organizational structure of the proposed database system

6. CONCLUSIONS

The assessment study of existing bridges in Vietnam showed many shortcomings on concrete structures that affect their physical condition and serviceability. The main deficiencies observed were catastrophic failure, chloride damage, structural damage, premature aging, and construction and design defects. Information collected from visual inspection, personal interviews and public media indicated overloads and over-use, vehicle collisions, adverse climate, poor design and construction practices, lack of preventive and essential maintenance, etc., as the main causes of these problems. In addition, country-specific causes are also found in Vietnam such as inappropriate bridge standards, direct attacks of bombs, missiles and explosions during elapsed wars and missing of bridge inventory data.

In order to overcome current problems of concrete bridges in Vietnam, the authors propose a series of diversified maintenance strategies. Firstly, proper implementation of site maintenance, defect monitoring system, and visual inspection as for tactical level can systematically control status of defect formation and essentially eliminate them. Finally, efforts are required for strategically changes of current maintenance management practice of Vietnam in order to develop appropriate bridge standards, control the creation stage of bridge, and implement good maintenance management system. These solutions help to eliminate outstanding problems and their potential causes currently occurring on concrete structures and enhance physical quality, capacity and functionality of existing bridges in Vietnam.

REFERENCES

1. Hai D.T., Yamada H., Katsuchi H., and Sasaki E (2006) Proposal of maintenance *management database for highway bridges in Vietnam. Journal of Structural Engineering, 52A.*
2. Hai D.T (2006). *Maintenance management system for existing bridges* – An explorative study. Doctoral Dissertation, Yokohama National University, Japan.
3. Hai D.T., Yamada H., Katsuchi H., and Sasaki E (2006) *A proposal of maintenance management system for existing bridges.* 3rd International on Bridge Maintenance, Safety and Management. Porto, IABMAS.
4. Hai DT., Yamada H., and Katsuchi H (2007) Present condition of highway bridges in Vietnam: An analysis of current failure modes and their main causes. *Journal of Structure&Infrastructure Engineering*, vol. 3, No. 1, 61-73.
5. Hai D.T (2009). Maintenance, Management, Life-Cycle Design and Performance. *Journal of Structure&Infrastructure Engineering*, vol. 5, No. 5, 381 – 394.
6. Hai D.T., Minh H., Mutsuyoshi H (2011) Reinforced concrete bridges in Vietnam – specific problems and proposed maintenance strategies. *Journal of Structure&Infrastructure Engineering*, vol. 7, No. 9, 689 – 699.