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- Technical Paper -

EXISTING CONCRETE BRIDGES IN VIETNAM: AN ANALYSIS OF DETERIORATION MODES AND THEIR MAIN CAUSES

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ABSTRACT

This paper was conducted to evaluate the status of bridges in Vietnam. The approach included literature reviews to identify deterioration with site inspections and personal interviews to ascertain their validity. Results show on overall picture of bridges in poor physical condition, thus providing poor service to users. The objective of this study is to clarify the current condition of existing concrete bridges in order to analyze the deterioration modes and their main causes. Further, the suggestion on the possible ways to improve the situation of concrete bridges was also proposed.

Keywords: Bridge, Causes, Failures, Highway, Maintenance, Vietnam

1. INTRODUCTION

Having been built decades ago and with the impact of the adverse climate, extreme traffic, natural calamities, etc., many existing bridges in Vietnam are now in critical condition. This has created a situation of a general lack of safety, degraded physical capacities and serviceability. This is requiring substantial expenditures and attention to repair and replace these deficiencies. Defect is generally considered to be nonconformity of performance against expectation (Feld and Carper [4]). These include cracks, distress, excessive deformation, settlement, premature material deterioration, construction defect, aging, etc., (Hai et al. [6]). It is necessary to diagnose all deterioration modes and indicate their causes so that accurate maintenance and management actions can be taken.

Highway bridges in Vietnam consist of a total 4,107 bridges, running a total length of 150,374m over the entire country (TMoVN [12]). They are classified in terms of their lengths, materials, construction time, deck widths and load-carrying capacities (Fig. 1). High percentage of bridges is in poor physical condition, causing problems for traffic users. Moreover, not much effort is given to analyze bridge conditions due to shortages of research funds, lack of care, etc., making more difficult to overcome these problems. The aim of this paper is to evaluate the current condition of highway bridges in order to find existing defects and their causes, and then suggest possible ways to improve this situation.

2. LITERATURE REVIEW

Many researchers and practitioners have given various descriptions of what constitute the defect of a bridge. For example, Moses [10] considers a bridge to have failed when it does not qualify within the realm of clarified standards and specifications. Specific defects that can lead to this include corrosion, fatigue, scouring, settlement, construction defect, and aging. Structural deficiency and functional obsolescence can be also considered (Dunker and Rabbat [3]). Deficient bridges are those that should be closed or that require immediate rehabilitation to remain operationally safe. Functionally obsolete bridges are considered to be those whose deck geometries, load-carrying capacities, space clearances, etc., no longer meet the traffic demand. Bridge quality degradation due to the lack of durability, integrity, and serviceability has additionally been mentioned by Moodi and Knapton [9]. These failures may occur during the construction period or later during the service lifespan, causing problems for bridge stakeholders (e.g. traffic users, owners, the society, designers).

In this paper the authors will define the term “failure” as the nonconformity of actual performances against initial expectations, leading to negative impact(s) on the bridge and its stakeholders. A failure is therefore considered as an unexpected occurrence such as structural collapse or the appearance of local defect(s) that prematurely degrade physical condition, load-carrying capacity, serviceability, safety, etc. This failure might negatively impact on the bridge stakeholders who as a result will suffer from economic loss, extra maintenance costs and cares, nuisances or unsafe traffic conditions.

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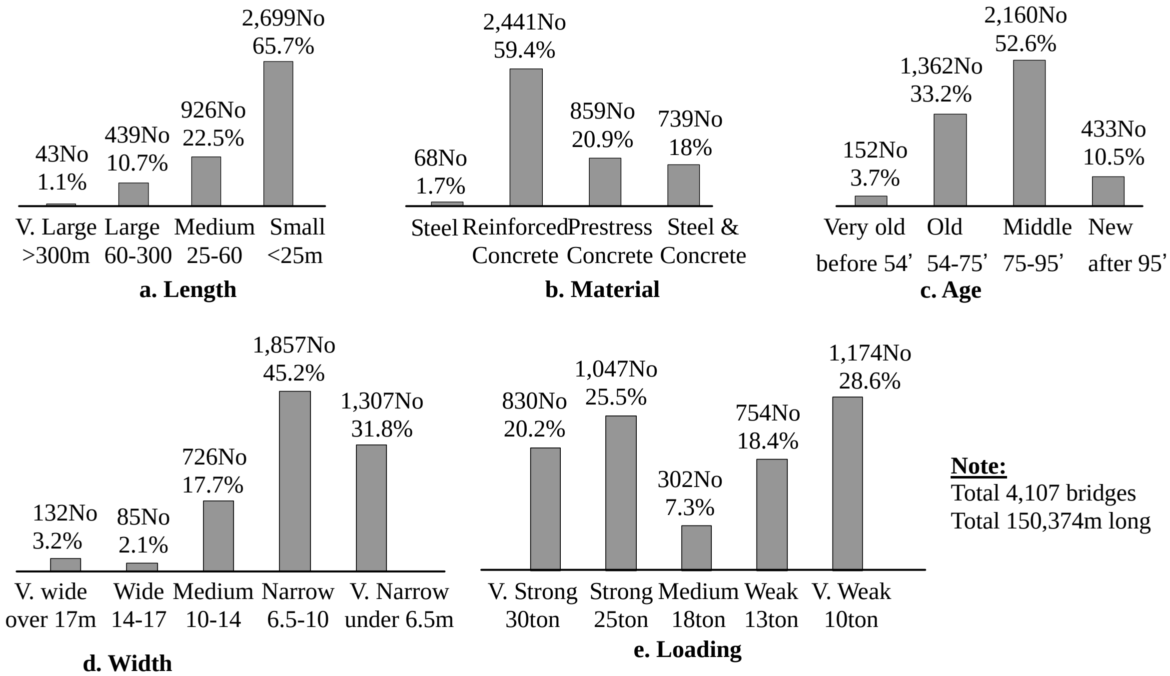

Fig. 1 Classification of existing highway bridges in Vietnam

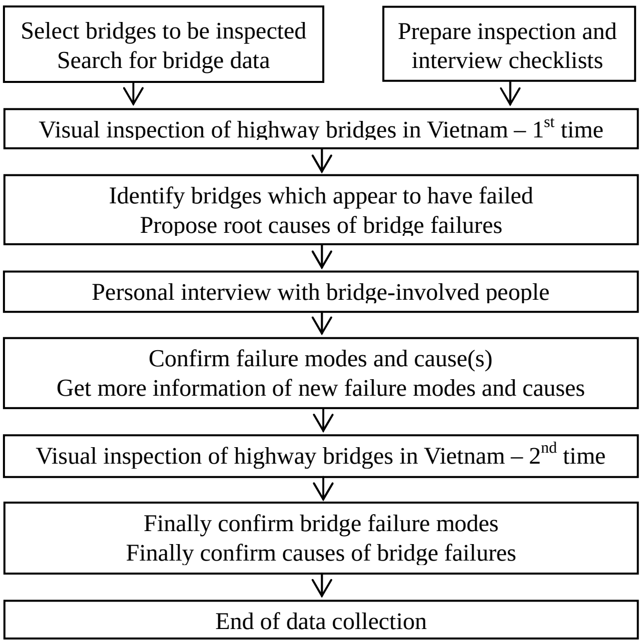

Fig 2. Visual inspections on highway bridges in Vietnam

3. RESEARCH METHODOLOGY

This research has been based on consecutive steps of identification of objectives, literature reviews, and visual inspections at bridge sites together with personal interviews, data analysis, conclusions and recommendations. Study objectives were selected to clarify the current condition of highway bridges in Vietnam, concentrating on those which appear to have failed. Literature reviews were comprehensively carried out on previous research to identify common problems currently happening on existing bridges throughout the world. However, some have been eliminated if the authors consider them extraordinary and having a low possibility of occurrence in Vietnam (for example, the defect of using deicing salt for ice and snow removal; damages caused by earthquakes or landslides). This screening is necessary in order to guide the research to the most important issues only. The literature findings helped the authors to prepare good checklists for visually inspecting bridges as well as suitable questionnaires for interviewing various parties such as the owner, management companies, maintenance contractors, and so on.

The data was collected from more than 100 highway bridges located in Vietnam and scattered between mountains, deltas and coasts. Preliminary visual inspection is to identify defect mechanisms and possible causes. The author afterwards interviewed local personnel (such as bridge engineers, maintenance supervisors, direct workers and governmental staff) who are closely involved in bridge managing and maintaining to confirm findings from the preliminary inspection. A subsequent site inspection was carried out to reconfirm all defects and their causes. Afterwards proposed maintenance solutions for improvement of the bridge condition were drafted.

4. GENERAL CONDITIONS OF HIGHWAY BRIDGES IN VIETNAM

The statistical data shown in Fig. 1a confirms that highway bridges in Vietnam are mostly in the small and medium size categories, accounting for 65.7% and 22.5% of the total respectively. Concrete is the most common material used in construction as reinforced concrete and prestressed concrete bridges encompass 59.4% and 20.9% of all bridges (Fig. 1b). Many weak/very weak and narrow/very narrow bridges are still in service although they can definitely not satisfy the requirement of modern vehicles (trucks, trailers, buses, etc) where there is demand for 25 ton and 14m width normally. Fig. 1e shows 28.6% and 18.4% bridges are in the 10 ton and 13 ton load-carrying capacities respectively. Meanwhile, 31.8% and 45.2% of bridges have traffic lanes less than 6.5m or from 6.5 to 10m width (Fig. 1d). Highway bridge's ages are in the medium range of 10 to 50 years with 52.6% bridges built in the period of 1975-1995 and 33.2% bridges built between 1954 and 1975 (Fig. 1c).

In general, highway bridges in Vietnam have wide range of shapes, commissioning dates, and have been built by various different design standards. Some have been subjected to the impact of wars, the adverse climate, and poor maintenance and management conditions (TMoVN [13]). Meanwhile, there are differences occurring from geographical locations due to scattering through mountains, deltas and coasts; and the climate as the northern area has four seasons and the southern area only has rainy and dry seasons. An extreme increase in vehicles carried in terms of volumes and weights are moreover adversely impacting the current condition of bridges. There is an assumption that bridges built after 1995 in Vietnam can satisfy current traffic demands as increased safety factors have been used in design stages. However, it seems that many bridges built before 1995 are not adequate for current transported loads and jams, especially those which were affected by wars.

5. CURRENT DEFECTS AND CAUSES

Existing concrete bridges in Vietnam are generally in poor physical condition and serviceability with several outstanding problems (Hai et al. [6]). These problems are from not only the bridge structures themselves, but also other aspects of current traffic, the society, highway routes, etc., such as:

- There are many unsynchronized bridges closely located along the same route tracks whose load-carrying capacity and deck width are very much different. This is because of the difference in construction time, design standards, used materials, and so on.
- Bridges and roads are not homogeneous. There are many bridges classified in weak/ very weak and narrow/very narrow categories. Meanwhile, highway roads are considerably strong and wide. This causes the occurrence of traffic congestions and jams occasionally at bridge locations.
- There are many deteriorated and obsolete bridges which are over 50 years old or under 13 ton load-carrying capacities still in service. They should be immediately replaced to ensure safe and smooth traffic.

The site investigation unveiled that much damage has been currently occurring on highway bridges in Vietnam, though they vary widely according to locations, bridge categories, the climate, design standards, construction materials, commissioning dates, and so on. Several common types of failure, sorted in order of seriousness and frequency, are analyzed as follows:

5.1 Corrosion

Corrosion of bridge elements is the destruction of metal and mainly occurs due to the oxidation of iron when exposed to an adverse environment (Ahmad [1]). The literature was proven to be correct when the site inspection found corrosion on all inspected bridges (Table 1). The extent of the damage was quite considerable for many of the highway bridges that are over 10 years of age. This paper, which refers to local research (Nguyen [11]) that surveyed and measured corrosion on 100 highway bridges as the reduction of rebar areas inside concrete structures. The electrical half-cell method that complies with Vietnamese standard TCVN 294:2003 (equivalent to ASTM C876) was employed. Results indicate that although rust appears in the upper-structures of almost all surveyed bridges, in general it is not serious. At several locations, however, up to 30% of the cross-sectional areas of steel elements have been penetrated by corrosion. Superstructures in areas above water level have been heavily corroded and have caused rebar cross-sections to disappear by up to 80%, concurrently with the occurrence of cracks and spalling on their surfaces. Even less corroded, tide-zoned structures still show moderate damage in the form of rust signals, which could be visually observed in up to 50% of steel areas. Submerged structures can be considered in good condition with not much corrosion occurring on their surfaces.

5.2 Fatigue damage

Even though superior materials (e.g. concrete and steel) have been used in bridge construction, there are many types of fatigue such as cracks, spalling, deformation, etc., still occurring (Kawamura [8]). The visual inspection confirms the problems reported in the literature, finding various degrees of fatigue damage on almost all surveyed bridges (Table 2). While critical damage has caused several bridges to suddenly collapse every year, local fatigues have progressively degraded physical condition, structural capacity and serviceability of bridges in Vietnam. Cracks are currently found on concrete surfaces, especially vertical cracks on superstructures due to shearing forces and traffic vibrations. Spalling can be seen 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.

5.3 Functional obsolescence

An obsolete bridge is defined as that whose deck geometry, load capacity, space clearance, roadway alignment, etc., no longer meets the transportation requirements (Chang et al. [2]). Results obtained from the visual inspection and the analysis of bridge inventory data indicate several aspects of functional obsolescence in Vietnam (Table 3) for:

- Low load-carrying capacity: a total of 18.4% and 28.6% highway bridges are classified as belongings to the "weak" category (13 ton) and the "very weak" category (10 ton). They are considered not to be normally satisfying current traffic demands of 25 ton.
- Narrow deck: the difference between wide roads and narrow bridges cause traffic congestions. Highways have been mostly built or upgraded recently to 32m width. Meanwhile, most bridges were built a long time ago and are less than 17m width, but have to serve trains, bicycles and pedestrians at the same time.
- Low space clearance: This prevents vehicles from crossing under bridges. Many bridges have space clearances lower than 3.2m, so can not satisfy for modern vehicles of 4.5m height.

5.4 Aging

The problem has become more critical now as there are more incidents of failures related to old bridge structures (Hanna and Jones [7]). Most highway bridges in Vietnam were built from 10 to 50 years ago. However, premature aging signs could be visually found 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. These have lead to a decrease on the physical condition of bridges. In addition to the premature-aging problem, there are currently 152 bridges or 3.73% of the total number having ages over 50 or even 100 still in service. They are considered very old and not having the structural and functional abilities to serve for modern traffic (Table 4).

5.5 Human invasions

People invasions of bridges are not much mentioned in the literature; however it is a common fact in Vietnam. Highway bridges are occupied for many purposes (Table 5). The clearance spaces are used generally as flea-markets or street-front shops while their abutments can be used as anchorage points for vessels and barges. There are many bridges that had pedestrian lanes invaded by residential sellers and pass-over buyers to trade local goods and products. These practices have created many problems such as narrowing of traffic lanes, creating congestions and jams, occurrence of fatigues, and so on. These problems reduce bridge serviceability. They cause the appearance of defects to adversely impact on bridge quality.

5.6 Construction defects

Problems that originated during construction periods have an adverse and expensive impact on in-service bridges. They account for an extra expense of up to 7.5% of the total construction costs and cause the physical condition and serviceability of existing bridges to degrade rapidly (Feld and Carper [4]). Defects occurred during the construction period are widely reported on many recently built bridges in Vietnam, while there is no record available on aged bridges. The available evidence and records can primarily recognize poor quality of concrete, rebar, paint, etc., as the main causes of the problem. Inaccurate layouts regarding thickness, dimensions, elevations, etc., of bridge components have been additionally detected in Vietnam, which decrease structural capacities and serviceability. Other problems are honeycombs, shrinkage and temperature cracks, poor connections and joints, and so on.

5.7 Scouring

Bridges built in or near rivers, seas and other channels can be vulnerable to scour due to the flow-induced erosion of soil materials from around their foundations, piers and abutments (Ghosn and Johnson [5]). The site inspection observed scouring symptoms occurring on highway bridges in Vietnam, however mostly they were not severe. Bridges classified within the "medium", "large" and "very large" categories mostly had preventive designs and solutions against scouring problems, therefore adverse impact on substructures was generally minimized. The site visual inspections and the interview of bridge-involved personnel however unveiled several scouring symptoms on small bridges. These symptoms are erosions of piers and abutments, soil movements, formations of holes underneath foundations, settlements, washing of protected embankments, and so on.

5.8 Settlements

When being loaded, bridges will settle due to compressions of the ground underneath. If an actual settlement exceeds the allowed one or there is a major difference in settlements, damage may occur on their structures concurrently with the appearance of extra stresses and over-displacements (Moses [10]). The different settlement is occasionally recorded in Vietnam to create unexpected restrain displacements among bridge components. Extra internal forces occur soon afterward as the result of these displacements to cause fatigues in the superstructures and over-widen expansion joints. When the problem is definitely unavoidable, it is of course allowed as a factual factor to be counted for in designs. Several bridges in however experience actual settlements exceeding the allowable level, which lead to the bridge becoming structural deficiencies or functional obsolescence, means that bridges either have a different elevation to approach roads or that they will have a lower space clearance. This causes difficulties in accessing from/to or under them.

Table 1. Current situation of corrosion and the 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, salt air, change in temperatures, etc
Superstructures (2m above water levels)	Frequent (70% bridges)	Serious (maximum for 80% steel areas)	Lack of protective coats for concrete surfaces.
Tide-zoned structures (up to 2m above water)	Sometimes (40% bridges)	Moderate (maximum for 50% steel areas)	Poor quality of protective coats for metal surfaces.
Substructures (under water levels)	Rare (15% bridges)	Not happen (only few corrosion signals)	Thinness of concrete covers is only 15-50mm thick.

Table 2. Typical fatigue damage occurs on inspected highway bridges in Vietnam

Fatigue damage	Occurrences	Degrees	Main causes
Structural collapses	Very rare (random only)	Very serious	Traffic overloads (increased weight of vehicles) and overuses (increased number of vehicles).
Cracks	Frequent (70% bridges)	Serious	Traffic jams and congestions.
Spalling	Frequent (70% bridges)	Moderate	Exceeded collisions of large moving vehicles and vessels.
Damage of deck surfaces (tears, concaves, convex)	Sometimes (40% bridges)	Moderate	Other causes of bombs and explosions, external impacts, construction defects, etc

Table 3. Summary of functional obsolescence

Functional obsolescence	Occurrences	Degrees	Main causes
Low loading capacities	Frequent (70% bridges)	Serious	Enormous changes of future conditions against initial design assumptions
Narrow decks	Sometimes (50% bridges)	Serious	Differences between bridges and roads for widths and load capacities
Low space clearances	Rare (25% bridges)	Moderate	Lacking of proper bridge management systems to store and update bridge data
Others (unsuitable locations, over-slope, non-alignment)	Rare (random only)	Moderate	Other causes of climate impacts, material degradations and aging, fatigues, etc

Table 4. Summary of aging problems

Aging problems	Occurrences	Degrees	Main causes
Aging bridges with ages 50 years upward	Very rare (3.73% bridges)	Very serious (may collapse)	Adverse climates with high humidity, salt airs, heavy rains, etc.
Signals of shipworms, mosses and funguses	Frequent (80% bridges)	Light (surfaces only)	Lack of proper maintenance to remove aliens off bridge surfaces.
Material cancers of decays, erosions, spalls, etc	Frequent (70% bridges)	Moderate (lightly in superstructures)	Use unsuitable and not durable materials against weather attacks. There are many old bridges in services

Table 5. Summary of human invasions

Human invasions	Occurrences	Degrees	Main causes
Invading deck surfaces	Sometimes (40% bridges)	Serious	Bridges locate at ideal locations where there are many vehicles and people using them
Invading clearance spaces	Frequent (70% bridges)	Moderate	Lack of strict protection and imposed actions against alien intruders
Invading substructures of piers and abutments	Rare (30% bridges)	Moderate	The history creates many bridges without clear boundaries against surrounding areas

Table 6. Settlements are observed on inspected bridges in Vietnam

Settlement	Occurrences	Degrees	Main causes
Different settlements among bridge foundations	Very rare (10% bridges)	Moderate	Unclear and undermining of soil conditions. The current regulations require for 5% random investigations only to minimize costs.
Over-settlements of foundations	Very rare (10% bridges)	Moderate	Bridges were designed with unsuitable foundation solutions against actual settlements

6. CONCLUSIONS

The research explored the current status of highway bridges in Vietnam and analyzed the failure modes and their main causes. It unveiled that existing bridges are in a state of poor physical and serviceability condition with corrosion, fatigue, functional obsolescence, construction defects, and aging were identified as the common and critical deterioration modes. On the other hand, human invasions had not been indicated in past research, but additionally detected in Vietnam. The causes of these problems according to the literature are overloads, traffic jams, collisions, the extreme environment, poor construction quality, and lack of site maintenance. These have proven to be also true for the case of Vietnam. Additional causes that are not widely known throughout the world such as missing of inventory data, the impact of wars, sand exploits and burglaries occurred on highway bridges in Vietnam.

This research suggests firstly that all available resources should be focused to remedy the most serious defects. Preventive maintenance should be given priority to eliminate causes of potential problems. Meanwhile, corrective maintenance must be regularly carried out to remove existing defects. As a long-term goal, the recommendation emphasizes establishing an adequate maintenance system. This will help in the setting up of proper inspection and maintenance manuals together with carrying out defect prevention and correction programs. Moreover, regular training to teach all involved parties to identify failure modes, their causes, and prevention and correction solutions is compulsorily required. The government of Vietnam who acts as bridge owner should provide adequate fund in order to compensate for expenses of required maintenance and management. As the fund is currently very low and comes solely from the government budget therefore only if extra resources are mobilized from private and foreign sectors this goal can be accomplished. This suggests the government of Vietnam should make new policies that allow private and foreign sectors to construct, operate and maintain highway bridges via several new forms of Build-Operation-Transfer, Build-Operation, Build-Transfer, and so on.

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