Análisis de la evolución de los daños en los puentes de Colombia

Analysis of the evolution of damage in the bridges of Colombia

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Resumen

Se presenta la identificación y evolución de daños en casi dos mil puentes de Colombia, para tres periodos de inspección (1996-1997, 2001-2002 y 2007-2008), basándonos en levantamientos presenciales realizados en el Instituto Nacional de Vías de Colombia (INVIAS) con la metodología del Sistema de Administración de Puentes de Colombia (SIPUCOL). Para ello, se realizó un arduo trabajo de consolidación de los daños que se presentaron en los componentes principales de los puentes, tipificación, calificación, sus niveles de durabilidad, estabilidad y servicio, así como la evaluación de las obras de mantenimiento y rehabilitación implementados, con los cuales se procedió a los análisis y comparaciones por período. Así, se pudo concluir con la identificación de los grupos de puentes en buen estado, los de condiciones regulares y aquellos con daños graves y riesgo de colapso, las medidas urgentes de previsión y reparación que se detallan, así como el aporte a procesos de diagnóstico y procedimientos para inspecciones especiales. Por otro lado, la sola implementación del Sistema de Administración de puentes en un país entero, es una experiencia procedimental importante que deseamos sirva de referencia para otros diagnósticos y para el consolidado del estado de los puentes en América Latina en los temas de conservación y recuperación.

Palabras Clave: Puentes, inspección, mantenimiento, rehabilitación, daños

Abstract

In this document the identification and damage evolution of nearly two thousand bridges in Colombia is shown during three evaluation terms (1996 – 1997, 2001 – 2002 and 2007 – 2008). The main recognition bases were the surveys developed by the National Roads Institute (INVIAS), by including the methodology by Colombian Bridge Management System (SIPUCOL). Special efforts were made to identify damages undergone by bridges main components including typification, qualification, durability levels, stability and service operation; as well as the assessment of implemented maintenance and restoration tasks, which were used for the analyses and comparisons per period. The identification of bridges was concluded, sorting the bridge conditions, from bridges in good conditions to those with major damage and risk of collapse. Preventive and corrective actions are also described, as well as the contribution to diagnoses processes and procedures for additional inspections. On the other hand, the mere implementation of the Bridge Management System in the whole country is a positive know-how achievement we wish to share as a reference for further diagnosis of bridges conditions in Latin America regarding conservation and restoration issues.

Keywords: Bridges, inspection, maintenance, restoration, damage

1. Introduction

Bridges are road's major infrastructure civil works in a country, in this case Colombia. Therefore, the purpose of engineers is to ensure their conservation and their security operation conditions. This significant task is achieved by applying an integral Bridge Management System, which involves inventory, inspection (diagnosis), loading capacity, and maintenance and restoration activities. In order to achieve such objectives, in 1996 the INVIAS implemented the Bridge Management System in Colombia (SIPUCOL), so as to improve and support technical and administrative management of bridges in this country. They implemented five modules: Inventory, main inspection, special inspection, routine inspection and loading capacity. Particularly, main inspection module consists of a visual inspection to evaluate each component in a bridge, where the structure condition is identified as well as damages and required restoration measures, thus providing a classification based on a previously defined qualitative scale (National Roads Institute et al 1996).

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Figure 1 shows the method resume for the main inspection implemented on each diagnosed bridge.

Figura 1. Resumen metodológico de la inspección principal (Muñoz, E. et al., 2004)

Figure 1. Methodologist Summary of the main inspection (Muñoz, E. et al., 2004)

Since 2002, the Structures Team of the Pontificia Universidad Javeriana has developed a research on the condition and typical damages existing in Colombian bridges [(Muñoz E., 2001), (Muñoz E. et al., 2004), (Muñoz E., 2006), (Muñoz E. et al., 2008) and (Muñoz E., 2013)]. This research was based on the results provided by visual inspections developed by the INVIAS during the years 1996-1997 (1995 bridges inspected) and 2001-2002 (2399 bridges inspected). Such research was supplemented by including the results of inspections carried out by the same institution during the period 2007-2008 (2633 bridges inspected). Particularly, our research team organized, analyzed and provided recommendations and conclusions for the bridges in our country.

This task demonstrates our purposes on these topics, which are summarized as a contribution to the best results achieved by SIPUCOL, due to their undeniable benefit for bridges good conditions and, therefore, to maintain a contributive support to the economical development of our country. An additional purpose is to organize the procedure experience of this research, so that it can be used as a reference for further diagnoses; to broadcast and achieve a shared development with other research teams on this subject. Besides, the most relevant results of this research are included in the bridges engineering book, which is still under elaboration (Muñoz E., 2011).

2. Work development

2.1 Diagnosis on the work site Main Inspection

2.1.1 Tread Layer

Widespread chippings and pot holes have been found in asphalt tread layer bridges, as well as typical map crackings (Figure 2). Concrete tread layer bridges show material wearing out due to water flooding, combined with the pavement insufficient structural capacity due to the gradient and poor water-runoff manipulation on decks (inadequate pumping and lack of drainage systems).

Figura 2. Carpeta descompuesta, grietas de cocodrilo

Figure 2. Damaged layer, map-cracking

It was concluded that the condition of the tread layer remains stable, as the classification percentages did not change during the analyzed periods (Figure 3). Breaking down is the most frequent damage. The suggested restoration measurement is the replacement of asphalt layer, as well as the increase of the maintenance program.

Figura 3. Estado de la superficie de rodadura

Figure 3. Tread Layer condition

2.1.2 Expansion Joints

One of the problems suffered by this component is the blockage due to external elements, which affect horizontal and vertical movements beard by the joint (Figure 4). Above may cause a pier ring's wearing out, thus allowing water to go through the joint affecting the bridge's bearings, abutment pier and piles.

Figura 4. Junta sin sello y cubierto con tierra

Figure 4. Joint lacking of pier ring, covered with earth

In some cases this damage is caused by the access embankment seatings provoking a level difference with the bridge superstructure deck, thus creating an increased vehicular impact. In the same way, damage can be caused due to structural design shortcomings, which means that the component does not have the capacity to resist deformations between the access area and the bridge's deck (Figure 5).

It happens when the selected pier ring is not adequate, which depends on the bridge type, its typology and length (non-joint functioning), such as abutment pier diaphragms and slab, among others. This problem is reflected by the wearing out and detachment of its components due to an inadequate configuration, as well as the increase of vehicular impacts (Figure 6).

The inadequate designs of the area next to the joints, (where water flooding problems take place later affecting this device's components) create infiltration conditions, which accelerate deterioration and damages bridge components adjacent to this device.

Damage can also be caused by corrosion of angles and fixing plates which are part of steel joints; inadequate welded connection between angles and fixing plates; failure of end plates fixing the joints components with the adjacent elements of the bridge (slab, diaphragm, etc.); inadequate construction of roadside posts due to concrete's lack of adherence or poor quality; increase of the expected allowable loads; or dropping inadmissible chemical components affecting the caulking compound employed for the installation.

Figura 5. Deterioro de junta cubierta de mezcla asfáltica
Figure 5. Damage of joint covered by asphaltic layer

Figura 6. Falla unión soldada en junta de acero. Soldaduras intermitentes
Figure 6. Welding failure of steel joint. Non continuous welding

It was found that components classified as “defective ones” decreased from 14% down to 2% (Figure 7). The most frequent damage during these inspections was infiltration. The suggested restoration action is the replacement by rubber asphalt and the increase of maintenance tasks.

Figura 7. Estado de juntas de dilatación

Figure 7. Expansion joints conditions

2.1.3 Sidewalks, curbs and safety fences

Typical damages suffered by these components are concrete honeycombing together with exposed steel bars, due to deficiencies of construction processes and/or poor design, as well as structural crackings (Figure 8) and non structural crackings due to contraction, concrete shrinking, etc. Concrete durability deficiencies, in some cases caused by carbonation (PH loss), sulfates, organic matter and chlorides. Typical damages taking place in safety fences` components are mainly caused by trucks and vehicles accidents (Figure 9).

Figura 8. Bordillo descompuesto

Figure 8. Damaged curb

Figura 9. Barandas inestables por impacto

Figure 9. Unstable safety fences due to collisions

It was found that the condition of sidewalks and curbs was improved, since the number classified as “defective ones” decreased and the number classified as “good ones” increased (Figure 10). The most frequent damages detected by such inspections are collisions and others (garbage, sand and bush accumulation, etc). The suggested restoration is concrete repair and the increase of maintenance tasks.

Figura 10. Estado de andenes y bordillos

Figure 10. Sidewalks and curbs conditions

The safety fences condition improved as the number of components classified as “good ones” increased. The most frequent damages detected by these inspections are collisions and others (garbage, sand and bush accumulation, etc). The most suggested restoration is the replacement of the safety fence and the increase of maintenance tasks (Figure 11).

Figura 11. Estado de barandas

Figure 11. Safety fences conditions

2.1.4 Cones and land slopes

Instability of land slopes adjacent to the bridge's wing-walls and abutment piers, due to erosion or undercutting. Above is detected by the slow landslide where a surface failure is not distinguished. The land surface shows some step faulting and the trees trunks lean towards the movement direction. Forward rotation of one or several rock or soil blocks around a point or pivot rotation in lower section. Translation land slide which is the displacement of soil or rock mass alongside a plain or crackled failure surface. The reasons for this kind of damage are erosion of land slopes adjacent to the pier abutments, mainly because of the lack of devices to handle run-off water coming from the highway during winter season and; the instability of cones and land slopes due to a poor filling configuration and land slopes affectionation due to lateral undermining effect (Figure 12).

Figura 12. Deslizamiento del talud adenaño del puente que afecta los conos y taludes del puente.

Figure 12. Land slide of land slope adjacent to the bridge affecting bridges' cones and land slopes

This component condition remained constant during inspection periods. The suggested repairing task is the construction of ditches (Figure 13), in order to avoid land slopes erosion.

Figura 13. Estado de conos y taludes

Figure 13. Cones and land slopes conditions

2.1.5 Wing-walls

Structural instability of bridge wing-walls is caused by seating and/or undermining effect; thus risking the access embankment stability. This is evidenced by means of wing-wall crackings and/or rotations visually identified. Such damages are detected when movements and landslides take place due to lateral undermining of the river bed on the wing-walls foundations (Figure 14 (a)); erosion due to adjacent land slopes instability affecting wing-walls stability (Figure 14 (a)) and; due to deformations or wing-walls rotations due to foundation seatings provided that these components are not structurally prepared for such conditions (Figure 14 (b and c)).

Figura 14. (a) Falla de aleta por socavación. (b). Grietas por falta de capacidad de carga de las aletas, producidas por un probable asentamiento. (c) Asentamiento en terraplén de acceso que afecta la aleta

Figure 14. (a) Wing-wall failure due to undermining. (b) Crackings due to lack of wing-walls loading capacity, probably caused by seating. (c) Access embankment seating which affects the wing-wall

Another kind of damage of this component is deterioration, which affects its loading capacity and therefore, its ability to bear horizontal loads transmitted by the access embankment. Deterioration may be caused by structural deficiencies due to an inadequate structural design (inadequate geometry, foundation fixed by an inappropriate abutment pier (see Figure 14(b)); the inadequate use of this component to bear loads due to the enlargement of the bridge deck or walkway (it happens when the bridge deck is enlarged and the use of wing-walls is selected to bear this new structure). Brush or garbage accumulation, deficient construction processes (honeycombing and exposed steel bars), durability problems (carbonation and PH loss, high sulfate or chloride contents) considerably affect this component. Generally, the condition of this component is good. The kind of frequent damages detected by these inspections are seating, erosion and undermining. The suggested restoration task is to repair concrete and to increase maintenance tasks (Figure 15).

Figura 15. Estado de aletas

Figure 15. Wing-walls Conditions

2.1.6 Abutment Pier

The structural instability of abutment pier, due to seating and/or undermining, affects the superstructure stability as well as the wing-walls and access embankment of the bridge. When damage is caused by seating, it is evidenced by the abutment pier structure rotation, detachment between the abutment pier and the wing-wall, abutment pier crackings, etc. When damage is caused by undermining; it is evidenced by the bearing capacity loss of abutment pier foundations, thus observing: exposed piles, holes in the surface foundation pivots, etc.

Another type of damage is the deterioration or the lack of loading capacity of this component, which is evidenced by structural deficiencies due to an inadequate design, where the component is not able to bear the earth lateral thrust produced by the access embankment neither the vertical loads from the bridge superstructure (Figure 17). Above is evidenced by the presence of crackings, specially reflecting crackings (crackings in the bearing area). Deficient constructive processes (honeycombing and exposed steel bars), as well as concrete durability problems (due to carbonation or PH loss, sulfate and chloride contents) generate corrosion problems (Figure 18).

In the same way, failures caused by concrete crushing on the abutment pier in the bearing area, due to the lack of loading capacity; damage of pier abutment concrete due to infiltration from the expansion joints (non-sealed and permeable). Besides, garbage or brush accumulation affects this material component in the medium term.

Figura 16 . Grieta horizontal en la mitad de la altura del estribo

Figure 16. horizontal cracking at the mid height of the abutment pier

Figura 17. Problemas de capacidad de carga
Figure 17. Loading capacity problems

Figura 18. Pérdida de sección de refuerzo principal por problemas de corrosión
Figure 18. Loss of main reinforcement section due to corrosion effect

The condition of this component is good. The most frequent damage type detected by this inspection is infiltration. The suggested restoration is to repair concrete and increase the maintenance tasks (Figure 19).

Figura 19. Estado de estribos
Figure 19. Abutment piers conditions

2.1.7 Piles

Deformations or piles rotations due to their foundation seating provided that this component is not structurally prepared for such conditions. Such kinds of seatings are evidenced by safety fences longitudinal deformations. Movements and landslides are caused by the river bed lateral undermining in the piles foundations (Figure 20).

Figura 20. Material de soporte de pila afectado por socavación

Figure 20. Bearing pile material affected by undermining

Another damage type of this component is deterioration and the lack of loading capacity, which is detected by structural deficiencies not allowing the pile to resist seismic loads neither vertical loads from the superstructure, thus provoking reflecting crackings and shear crackings. Deficient constructive processes (honeycombing and pile's exposed steel bars), as well as concrete durability problems (carbonation or PH loss, sulfate and chloride contents) generate corrosion, mainly under aggressive environments (Figure 21), specially in coast areas. Piles concrete deterioration due to infiltration from expansion joints (non-sealed and permeable) affect durability (Figure 22). Besides, the garbage and brush accumulation also affect this component material durability in the medium term.

Figura 21. Corrosión en el acero de refuerzo de pilas

Figure 21. Corrosion of reinforcement steel in the piles

Figura 22. Alta concentración de humedad

Figure 22. High moisture content

The condition of this component is good (Figure 23). The most frequent damage type is infiltration. The suggested restoration action is to repair concrete and increase maintenance tasks.

Figura 23. Estado de pilas
Figure 23. Piles conditions

2.1.8 Bearings

An inadequate design leads to seismic vulnerability on the bearing pier abutment and piles not structurally enabling them to endure an earthquake, thus risking the bridge overall stability. Generally, they are constructed overlooking the seismic resistance specifications. The vulnerability of bridge bearings is identified by an insufficient seating length, by its shape and inadequate dimensions (steel bearing outrigger, concrete and rollers outrigger), etc. There is a lack of transversal restriction devices or seismic stops ensuring the bridge lateral stability during a seismic event.

Another kind of damage of this component is deterioration, which is evidenced by several aspects such as deformation and neoprene bearing distortion; chipping under bearings due to concrete crushing in the abutment piers and piles; non lubricated mobile steel bearings (rollers); overall corrosion on steel bearings (Figure 24); bearing outrigger lacking of proper verticality; lack of anchoring or bearing bolts on mobile steel bearings; garbage or brush accumulation that affects this component material durability in the medium term; bearing deterioration either by coating layer poor quality or crackings due to bending of the end main reinforcement, which requires a significant curve radius for higher diameter rods.

Figura 24. Corrosión y deterioro del apoyo balancín de acero

Figure 24. Corrosion and deterioration of steel bearing outrigger

The condition of this component is good. The most frequent damages detected by these inspections are structural damage and infiltration. The suggested restoration action is the replacement of bearing and repairing concrete (Figure 25).

Figura 25. Estado de apoyos

Figure 25. Bearings conditions

2.1.9 Slab

Structural deficiencies are shown by means of reflection crackings (primary or secondary). There is a concrete deterioration, where exposed steel bars, honeycombing, construction deficiencies and durability problems are found. This diagnosis includes reinforced concrete access slabs. The main causes of slab damages are due to the poor loading capacity derived from an inadequate design. It happens when slab has a thickness lower than the one specified by Seismic Design Code (<18 cm); which is detected by its weaker consistency, signs of crackings and/or honeycombing (Figure 28). Slabs also have a plain reinforcement, with a diameter lower than 3/8" and, bar plates distance is higher than 30 cm between them, which does not allow an adequate bonding between concrete and steel. Also when there are significantly wide crackings, which are a sign of lack of structural capacity thus showing the slabs inability to resist higher stress than the one they were designed for (structural crackings). When crackings are thinner, they may be related to a durability deficiency (non-structural crackings). In order to achieve a reference in regards to durability, it is suggested to take in to account the recommendations by ACI 224 R-01 ("Control of Cracking in concrete Structures").

Tabla 1. Guía para ancho admisible de fisuras en estructuras de concreto reforzado bajo cargas de servicio

Table 1. Guide for admissible fissures widths in reinforced concrete structures under service load

Condiciones de exposición/ <i>Exposure conditions</i>	Anchos de fisuras admisibles/ <i>Admissible fissures widths</i>
Aire seco o membrana protectora/ <i>Dry air or protective membrane</i>	0.4
Ambiente húmedo (aire húmedo, suelo, etc.)/ <i>Humid environment (humid air, soil, etc)</i>	0.3
Productos químicos descongelantes/ <i>De-frost chemical products</i>	0.2
Humedecimiento y secado de agua de mar/ <i>Sea water drying and moisture processes</i>	0.15
Estructuras para retención de agua, excluyendo tuberías sin presión/ <i>Structures used for water runoff, excluding non-pressure piping.</i>	0.10
Elementos de concreto preesforzado/ <i>Pre-stressed concrete elements</i>	0.10

For diagnosis regarding cracking of this component, the following is recommended:

- If crackings widths are lower than 0.3 mm, it may be assumed that reinforcements are not high enough, so a further action shall not be taken. In such cases, this condition ranking shall be between 1 and 2. However, following up the cracking width is recommended in order to compare it in further inspections.
- If crackings widths are between 0.3 and 0.6 mm, the reinforcement may be high, but it is assumed it is not dangerous. Normally the classification ranking will be 3. When there is a fissure width higher than 0.6 mm, it indicates that reinforcements are high and there might be a problem regarding loading capacity. In these cases, classification will be 3 or more.

Deficient construction processes are evidenced by the presence of honeycombing and slabs' exposed steel bars (Figure 26) and; due to the presence of segregation and inadequate cold joints. There are slab crackings caused by steel corrosion, which makes steel to expand and swell up internally until creating longitudinal fissures, which are parallel to the reinforcement. Concrete fracture takes place in the upper cantilever beam together with primary and secondary reflective crackings (Figure 28). In the beam lower area; there also are relatively thin fissures, in netting shape, probably indicating loading capacity insufficiency. Fissures frequently take place in the roadway; a systematic fissure pattern on the asphalt layer often indicates there are problems with the slab. Concrete durability deficiencies caused by carbonation or PH loss on bridges. It means that concrete coating layer of this component is not properly protecting reinforced steel, leading to corrosion of steel. Deterioration may be the result of high sulfate and chloride contents in bridges built under aggressive environmental conditions. This is detected by the presence of non-structural crackings or concrete efflorescence (crystallized salt deposits located on a surface generally looking like whitish spots). Concrete may be beaten with a hammer so as to evaluate concrete consistency and condition.

Figura 26. Acero expuesto y recubrimiento insuficiente

Figure 26. Exposed steel bars, insufficient coating layer

Figura 27. Infiltración de la losa por deficiencias al tener drenes cortos

Figure 27. slab infiltration due to deficiencies because of short drains

Figura 28. Falta de capacidad de carga de la losa

Figure 28. Failure of slab loading capacity

Non-structural crackings due to shrinkage and setting, which thickness and way of spreading make identification easier. Concrete cantilever beams deterioration on bridges decks (Figure 27) is produced by the inadequate allocation of drains on the deck. It generates filtration or water blockades on the surface layer affecting the slab durability. It may be caused due to the following failures in the longitudinal drainage system:

- Insufficient amount of drains
- Drains having an inadequate section and length

This component is in good condition. The most frequent damages detected by these inspections are: concrete infiltration and concrete wearing out, exposed steel bars. The suggested restoration action is to repair drains and concrete (Figure 29).

Figura 29. Estado de losa
Figure 29. Slab condition

2.1.10 Beams

Structural deficiencies and deterioration of bridge beams, in some cases mean lack of loading capacity. It is reflected by shear, tension, flexure and torsion crackings caused by the insufficient beams loading capacity (Figure 30). Cross braces or transversal beams which have flexure and shear fissures. The presence of significantly wide fissures on main components of reinforced concrete bridges, show a loading capacity failure and prove they are enduring higher loads than the ones they are designed for (structural crackings). When crackings are thinner, they might be related to durability deficiencies (non-structural crackings). In order to achieve a reference point regarding durability, it is suggested to take into account the recommendations by ACI 224 R-01 01 ("Control of Cracking in concrete Structures") (Table 1).

Bonding failure between concrete and reinforced steel is caused by a poor structural specification (lack of hooks, wrongly allocated splices, flat reinforced steels, etc). It is identified by means of longitudinal fissures parallel to the reinforced beams. Overloading is produced by trucks transit on the bridges, which should be controlled by weigh stations. This kind of control should be also suggested for secondary and tertiary roads, which additional pavement thicknesses provokes overloading not considering that such structures are not prepared to bear an increase of dead loads.

Deficient construction processes are evidenced by the presence of honeycombing, segregation and beam exposed steel bars (Figure 31). Inadequate steel installation, inadequate stripping, lack of/improper concrete protection or curing process, lack of control on materials quality, inadequate coating layer and poor construction of cold joints. Concrete beams deterioration is caused by the inappropriate drains installation leading to infiltration, thus affecting components durability.

There are impacts on beams, which traffic runs underneath the bridge due to an insufficient clearance. Such impact affects concrete and main beam steel. The garbage and brushes accumulation affects this material component durability in the medium term.

Figura 30. Grieta a cortante en viga principal de concreto reforzado

Figure 30. Shear cracking on the main concrete reinforced beam

Figura 31. Acero principal expuesto y hormigueros en el concreto

Figure 31. Main exposed steel and concrete honeycombing

Other kind of damage is corrosion of pre-stressed or reinforced concrete beams, which generates a section loss affecting the loading capacity. This is evidenced either as reinforced beam corrosion or as durability deficiencies.

Corrosion produces crackings (generally parallel to the reinforcement) on concrete beams due to the section loss and swelling up of such reinforcement, thus decreasing loading capacity of such components (Figure 32). Durability is affected by carbonation, sulfate and chloride attacks (mainly in aggressive environment conditions, Figure 33). It is detected by means of non-structural crackings and efflorescence (crystallized salt deposits located on a surface generally looking like whitish spots). Concrete may be beaten with a hammer so as to evaluate concrete consistency and condition. Corrosion of structural steel beams are elements of mixed sections in bridges decks (concrete and steel), re-bars, arcs, suspension bridges, cable-stayed bridges and transitory bridges (Figure 33).

Figura 32. Corrosión por baja de pH y cloruros.
Figure 32. Corrosion due to loss of PH and chloride content

Figura 33. Corrosión e impacto, generó disminución de sección de viga
Figure 33. Corrosion and impact provoked a beam section reduction

The condition of this component is good. The most frequent damages types detected by these inspections are: concrete damage – exposed steel – and the lack of loading capacity. The suggested tasks are repairing concrete and refilling the crackings.

Figura 34. Estado de vigas, largueros y diafragmas
Figure 34. Beams, stringers and diaphragms conditions

2.1.11 Arc Elements

Structural deficiencies and deterioration of concrete, masonry or steel arcs were found in bridges. Such deficiencies are shown by fissures, signs of corrosion (color changes), exposed steel bars, honeycombing, etc. Such damages are caused by the lack of structural capacity showing transversal and longitudinal fissures in regular concrete arcs, which lead to loading capacity deficiencies (Figure 35).

Besides, there is lack of/loss of coating layer; honey combing and exposed steel bars. Due to a limited loading capacity, crackings took place on masonry arcs. Besides, settlements, segment displacements, crackings in bonding mortar and detachment of masonry units are found. There is excess of infiltrations that lead to material breaking up considerably affecting material durability (Figure 35). There are deficiencies of structural specifications for steel bridges, especially for welded joints between arc - king post and king post – stiffness beam. Distorted and disfigured elements show corrosion signs. Welding and painting deficiencies are present. Impacts by vehicles.

Corrosion of reinforced steel produces crackings on concrete arcs (generally parallel to the reinforcement), due to reinforcement section loss and swelling up. Such reinforcement section loss leads to a decreased loading capacity of such components, which function is particularly relevant. Concrete durability deficiencies are produced by a PH loss. It means that the concrete coating layer is not properly protecting the reinforcement steel, so it gets corroded. Its deterioration may be caused by a high sulfate and chloride content in bridges built under aggressive environmental conditions. It is detected by means of non-structural crackings and efflorescence (crystallized salt deposits located on a surface generally looking like whitish spots). Concrete may be beaten with a hammer so as to evaluate concrete consistency and condition. Bonding failure between concrete and reinforced steel is caused by a poor structural specification (lack of hooks, wrongly allocated splices). Overloading is produced by trucks running on bridges and, in some cases, by engineers involved in pavement restoration tasks, who incorporate additional pavement thickness on the bridge, not considering that these structures are not prepared to bear increases of dead loads.

Deficient Construction processes are evidenced by the presence of honeycombing and exposed arc steel bars, besides the garbage and brush accumulation affects the durability of this material component in the medium term.

Figura 35. Fisuras y eflorescencias

Figure 35. Fissures and efflorescence

The most frequent damages detected, by the inspections on this component, are structural steel corrosion, lack of loading capacity and infiltration. Its condition is good and suggested restoration tasks are repairing concrete and painting the steel (Figure 36).

Figura 36. Estado de elementos de arco

Figure 36. Arc Elements conditions

2.1.12 Wire and reinforcement elements

Durability problems of reinforcement elements and their connections are caused by corrosion effect that may compromise loading capacity. It is reflected as follows:

The overall corrosion of main elements of reinforced bridges (Figure 37) usually compromises the stability of the structure, specially the beads. Such corrosion is caused by the area environmental condition and, in many cases, because steel does not have a basic coating layer. Besides, there are welded joints wrongly constructed (undercuts between beads, discontinuity, inadequate casting) and crackings on tension elements.

The lack of blind rivets and bolts compromise the bridge stability. Beaten and corroded reinforcement elements, specially the upper bead, also risk the structural stability of the bridge. There is a deficiency of joints structural specification probably leading to excessive vibration (Figure 38).

Local and general buckling problems are endured by steel non-compacted reinforcement elements. It is detected when webs or wings are found showing local deformations. It is also caused when such components are lacking of bracings. There is a safety structural affection on the reinforcement components and connections due to fatigue phenomenon. Such phenomenon may affect elements, welded joints and bolt mounted connections on reinforced bridges. Such fatigue problems are identified by the following signs:

- External or internal fissures on welded units. Changes of welding color together with signs of minor corrosion.

- Partial or total welding detachment in several elements areas near the joints. Loose or damaged rivets, screws, bolts.

The accumulation of garbage and brush affects this component material durability in the medium term, due to the lack of cleaning and maintenance tasks.

Figura 37. Problemas de corrosión, pérdida de sección de cordón inferior
Figure 37. Corrosion problems, loss of section in the lower bead

Figura 38. Falta de pernos, problemas de vibraciones
Figure 38. lack of bolts, vibration problems

The condition of this component improved. The most frequent kinds of damages are structural damage and corrosion. The suggested restoration tasks are repairing the steel as well as painting steel.

Figura 39. Estado de armadura
Figure 39. Reinforcement condition

Structural deficiencies are shown by damaged wires and king posts on the bridges. This is reflected by corroded wires and king posts, which decrease the transversal section affecting structural safety. Deficiencies are also caused by lack of rivets in the beams area connecting with the king post; overall corrosion of steel elements; plates affected by buckling; inadequate structural specifications, increased fatigue phenomenon due to intermittent welding of main joints and welded elements; main wire threads breaking up (catenary and king posts) (Figure 40); lack of cleaning and maintenance tasks.

Figura 40. Catenaria principal con falla en alambres
Figure 40. Main catenary showing wires failure

Poor condition of this element increased. The most frequent detected damages are: structural damage and corrosion. The suggested restoration tasks are painting the steel and others (additional) (Figure 41).

Figura 41. Estado de cables, pendolones y torres
Figure 41. Condition of wires, king posts and towers

2.1.13 River bed

One of the main problems of Colombian bridges is undermining or foundation backfilling of abutment piers, wing walls and piles. Main causes are: river bed backfilling and sedimentation, which diminishes clearance and increases submersion risks. Insufficient hydraulic area and clearance (Figure 42) generates local and overall undermining due to the shrinkage of the superstructure foundation components in the bridge. Therefore, the river bed may affect the access embankments of the bridge and, in some cases, they may even collapse.

Consequently, a defective design leads to uncovered piles and abutment piers due to overall and local undermining.

Unnecessary obstacles are found (damaged trees, stones, houses, hydraulic structures, etc) in the bridge river bed, which produce local undermining (Figure 43). An inadequate bridge allocation occurs when there is a high flow attack angle or incidence angle towards the bridge infrastructure. Water flow attacks the piles and abutment piers horizontally thus reducing the effective river bed width (total width less the obstacles impact width). Therefore, water flow speed rises and the undermining depth also increases. There are unstable upstream water margins, which may affect bridges stability. The lack of a maintenance program in charge of cleaning rubbish and obstacles from the river bed also increases undermining.

Figura 42. Problemas de contracción del flujo

Figure 42. Flow blockade situation

Figura 43. Obstrucción en el cauce que genera socavación

Figure 43. Flow blockade in the River bed generating undermining

Figura 44. Puente Banadia. Puente que colapso recientemente por socavación

Figure 44. Banadia Bridge recently collapsed due to undermining

Structural deficiencies and corrosion of wires and reinforcement structure are damages which evolution has been unfavorable, since they have been frequently detected during the last inspection period 2007-2008. However, such damages have decreased for the remaining components, especially due to a reinforcement plan on bridges superstructure developed by the INVIAS.

It was found that the condition of components affected by concrete/exposed steel damage decreased. It was one of the most frequent damages found during the period 1996-1997, which is associated to construction processes deficiencies. The condition of slabs affected by structural deficiencies still remains. The reason may be trucks overloading or the lack of the slab loading capacity.

Infiltration damage affecting the slab decreased due to maintenance tasks, which consisted in cleaning and/or enlarging the corresponding drains placed on bridge decks.

The condition of components affected by undermining remained stable. It means that there is still an important percentage of undermining. Therefore, INVIAS is focused and prepared to face this phenomenon to take place. This damage is highly relevant provided that most of the Colombian bridges have collapsed due to undermining. (Muñoz, E.E., 2001)

3. Conclusions

A total of 1995 bridges were fully analyzed and compared during three assessment periods 1996-1997, 2001-2002 and 2007-2008). It was concluded that 67% of structures are in good condition (classifications 0, 1 and 2). The 28% is under regular conditions showing significant damages (classification 3). The remaining 4% has serious damages, risking collapse (classification 4 and 5) and they require urgent and immediate repairing jobs.

During the last inspection period, it was found that the number of components classified as "poor" decreased (classification 4 and 5) in comparison to the results obtained from inspections developed during the period 2001-2002, which is the result of maintenance and restoration tasks implemented by INVIAS (National Roads Institute). Similarly, the condition of components classified as "regular" (classification 3) did not change during the three (3) inspection periods. The condition of some components classified as "good" increased (classification 0, 1 and 2), while others showed no changes at all.

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