Failure Analysis

Guidance Materials

- **Road and Bridge Pathologies**
- **Toolkit User Manual**

Local Government Engineering Department
Local Government Division
Ministry of Local Government, Rural Development, & Cooperatives
Government of the People's Republic of Bangladesh

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গণপ্রজাতন্ত্রী বাংলাদেশ সরকার

Local Government Engineering Department

Failure Analysis
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Road and Bridge Pathologies, and Toolkit User Manual

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National
Resilience
Programme

The "Guidance Materials: Road and Bridge Pathologies; and Toolkit User Manual" is an essential document for Failure Analysis within a series of technical documents developed through a collaborative process between the Local Government Engineering Department (LGED) and the United Nations Office for Project Services (UNOPS). This particular document focuses on the Guidance Materials and is divided into two parts: Part-1 includes the Guidance Material for Road and Bridge Pathologies, while Part-2 provides the Toolkit User Manual.

This document is one of the deliverables of LGED and United Nations Office for Project Services (UNOPS) Sub-project, under the Joint National Resilience Programme (NRP) for the Government of Bangladesh. UNOPS provided technical assistance and advisory support to LGED in the implementation of the Sub-project.

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PREFACE

As part of the National Resilience Programme's Failure Analysis workstream, the Local Government Engineering Department (LGED) and the United Nations Office for Project Services (UNOPS) collaborated to develop a series of technical documents, including:

Diagnosis Report: This report aims to identify hazards and risk factors throughout the lifecycle of transport infrastructure (roads and bridges) in Bangladesh. It covers areas such as Governance/Legal Framework, Planning, Detail Design, Construction, Operation/ Maintenance, and utilizes a Forensic Engineering Approach.

Failure Analysis Framework: This report provides support documentation and a toolkit for assessing both shallow and deep causes of structural failures in rural infrastructure roads and bridges. It also identifies the triggering effects and the most likely origin of the failures.

Guidance Material for Road and Bridge Pathologies: It offers guidance for analyzing 15 specific pathologies related to rural infrastructure, including 10 for bridges, 3 for pavement, and 2 for embankment.

ToolKit and Toolkit User Manual: This document provides a toolkit along with a user manual. The toolkit supports the assessment of structural failures in roads and bridges, while the user manual offers guidance on how to effectively utilize the toolkit.

This specific document pertains to the Guidance Materials and is divided into two parts: Part-1 consists of the Guidance Material for Road and Bridge Pathologies, and Part-2 contains the Toolkit User Manual.

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PART-1: ROAD AND BRIDGE PATHOLOGIES

The Guidance Material has been developed for 15 pathologies (10 for bridges, 3 for pavement and 2 for embankment) in accordance with Failure Analysis Framework/report for the assessment of the Shallow and Deep causes of structural failures, the identification of the triggering effect, and most likely origin of the failure related to the life cycle of the structural design process of a rural infrastructure roads and bridges.

1.GUIDANCE MATERIAL: CONCRETE PATHOLOGY

○ Bearing malfunctioning

Bearing malfunctioning phenomena definition

The bearings are the elements in charge of transmitting the loads and movements of the deck to the substructure of the bridges: piers and abutments. There are different types of bearings depending on the loads and movements they have to transmit: strapped bearing pad, confined bearing pad, spherical, rollers, etc.

Bearing malfunctions are due to a poor design of the carried load, in the execution phase the poor levelling and sloping of the support devices can result in the ejection of the bearings. Other usual failures detected in the bearings are related to the degradation of the sliding material, and the material of the bearing itself.

These deteriorations imply the anomalous operation of the bearings, probably transmitting greater horizontal forces than expected to the infrastructure elements.

Some examples can be seen below:

The common shallow causes of bearing malfunction are:

- **Mechanical cause (ME)**:
  - Bearing excessive deformation/displacement/rotation
- **Environmental cause (EN)**:
  - Bearing aging

Bearing excessive deformation/displacement/rotation

Evaluation of the Shallow Cause (Primary Inquiries)

Numerous damages are detected in these elements due to an insufficient definition in the project, together with a deficient implementation on site. It is therefore considered necessary to define correctly these elements in the projects, as well as to indicate the values of their dimensioning in order to be able to recalculate, if necessary, different support devices due to the needs of the supplier or of the work itself.

Also, another anomaly can occur when the anchorage is insufficient to transmit the loads from the superstructure to the bearings, or from the bearings to the infrastructure. In those cases, bolts will break due to shear forces, causing the components to slide uncontrollably.

S.MC.XX Is the bearing excessively deformed, displaced or rotated?	
0	No, the bearing is well supported and it doesn't seem to have been displaced/deformed/rotated from its original position.
25	-
50	Displacement of the bearing is appreciated, or visibly the bearing is deformed/rotated
75	-
100	The parts of the bearing are displaced from its original position more than 25% of its length, the deformation or rotation of the bearing has surpassed the design limit of the bearing.
NO DATA	Bearings cannot be inspected
NON APPLICABLE	There are no bearings in the bridge

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

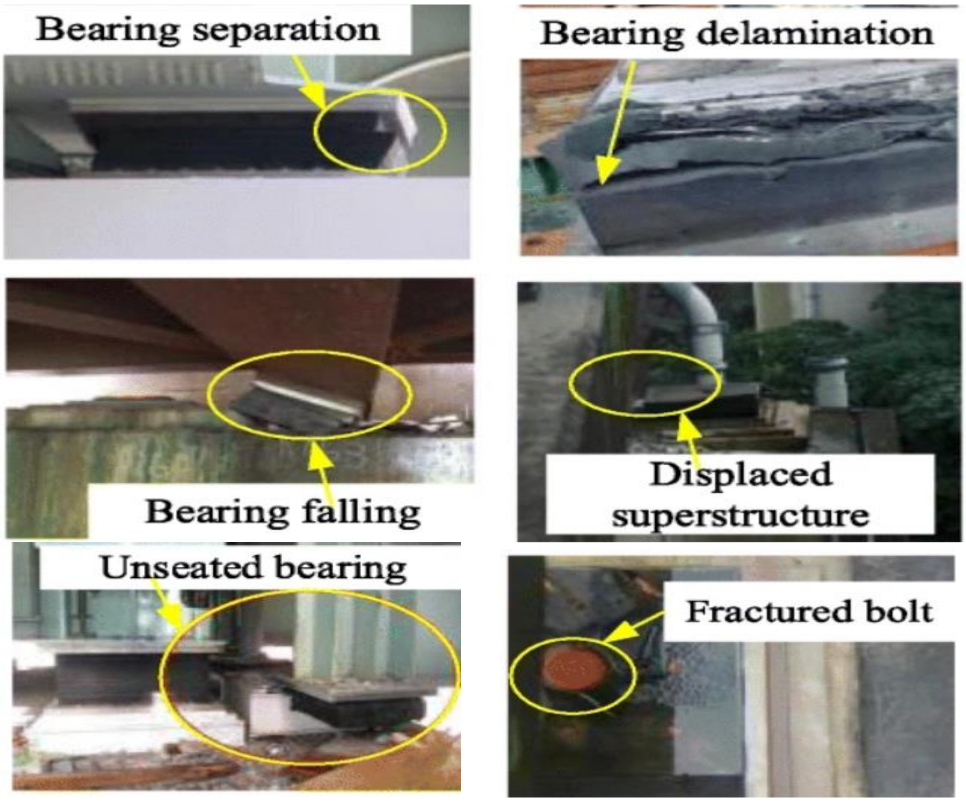
Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.DE.XX]* Has the bearings' expected design deformation been defined in the Set of Calculations?
- *[D.DE.XX]* Does the bearing Technical Specifications match the type of support in the theoretical model in the design?
- *[D.DE.XX]* Are the bearing anchors (type, diameter, position, and anchor length) specified in the Design Drawings?
- *[D.DE.XX]* Are the bearings locations clearly indicated in the Design Drawings?
- *[D.EX.XX]* Have the bearings been installed according to the specifications (location, height, and Temperature setting) as per the Design?

0	25	50	75	100	NO DATA	NON APPLICABLE
All the time	Often	Some of the time	Rarely	None of the time	No collected data	Non applicable or from previous questions

SCORING REFERENCE SYSTEM

Related image	Score
	0
	50
	100

Bearing Aging

Evaluation of the Shallow Cause (Primary Inquiries)

The replacement of these elements by designers and builders is essential, since they are fungible elements that degrade with the passage of time, so that at some point in the useful life of the structure it is necessary to proceed to their replacement.

S.MC.XX Has the bearing reached the limit of its lifespan?	
0	The bearing has been replaced, or has been properly revised and cleaned without visible cracks or has been recently installed and inspected.
25	-
50	Visibly the bearing has aged and incipient cracking is present. Further inspection in less than a year has to be done.
75	-
100	The bearing has reached the limit of its lifespan, has lost all the flexibility, visible cracks appear throughout the rubber and the functioning is compromised
NO DATA	The bearing cannot be inspected
NON APPLICABLE	There is are no bearings in the bridge

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.MN.xx]* Has the last inspection of the mechanical device been done less than two years ago?
- *[D.MN.xx]* Has the last maintenance of the mechanical device been done less than five years ago?
- *[D.MN.xx]* Is the mechanical device less than the specified Device Design Life (typically 15-20 years design life)?
- *[D.MN.xx]* Are the elastomeric pads cracked?
- *[D.MN.xx]* Are the mechanical devices NOT exposed to marine ambient?
- *[D.DE.XX]* Are drainage systems or minimum surface slope implemented to prevent water accumulation over the mechanical device?

0	25	50	75	100	NO DATA	NON APPLICABLE
None of the time	Rarely	Some of the time	Often	All of the time	No collected data	Non existing from previous stages

SCORING REFERENCE SYSTEM

Related image	Score
	**0**
	**100**

○ Corrosion

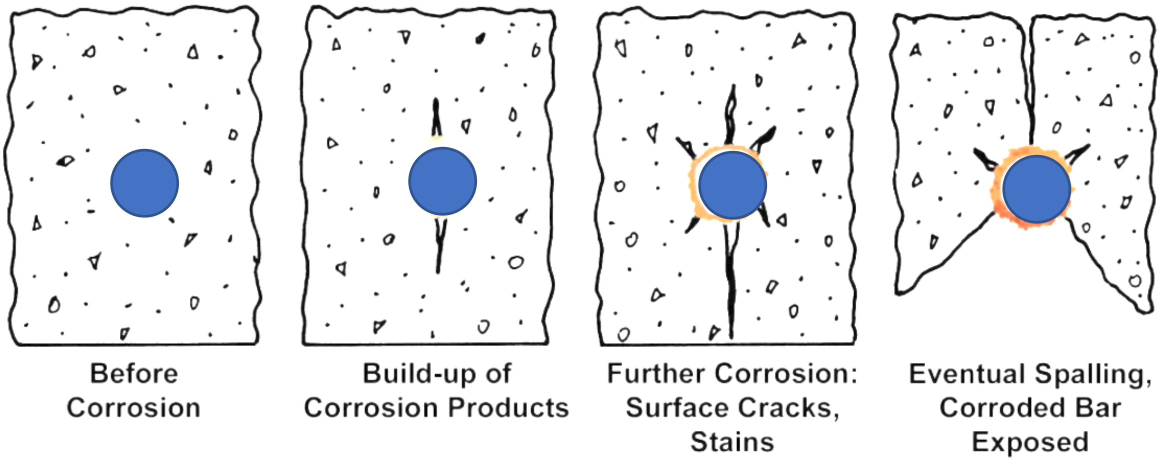
Corrosion phenomena definition

Corrosion of reinforcement is one of the most frequent types of damage to reinforced concrete structures.

It is manifested by the detachment of the concrete in a punctual or longitudinal way, leaving the reinforcement close to the surface without protection, so that over time they are covered by a film of rust that is manifested by the appearance of stains in the affected area.

Although there are several causes that can lead to the destruction of the passivation layer of the steel, in practice the factors that promote electrochemical corrosion of the reinforcement inside the concrete are mainly carbonation and the presence of chlorides, or both factors together, assisted by the cracking or porosity of the concrete that allows the passage of oxygen, humidity and various environmental aggressors to the reinforcement.

This type of pathology endangers the solidity of the affected elements and often requires costly repairs due to the repetition of a large number of identical elements.



The common shallow causes of corrosion are:

- Environmental cause (EN)
    - Presence of water/moisture
    - Exposure to chlorides
    - Fire exposure

Presence of water/moisture

Evaluation of the Shallow Cause (Primary Inquiries)

Water leakage is the main cause of early onset of corrosion and concrete deterioration as it acts as electrolyte. If the source of the water leakage or seepage is left unattended, it can cause structural damage. On the other hand, moisture present in the pores of the concrete reacts with the cement, causing corrosion in the reinforcement.

S.NV. Is the element of study visibly affected by water presence?	
0	There is no sign of water/moisture in the concrete nor in the rebars
25	-
50	Oxide marks are visible from the outside of the concrete cracks
75	-
100	The rebars are visible and moist to the touch
NO DATA	There are no signs of oxide marks nor seepage
NON APPLICABLE	The element has no rebars

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

2.2. Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.DE.XX]* Has the crack width been evaluated in the Set of Calculations?
- *[D.DE.XX]* Is the aggressivity of the environment properly defined and assessed in the Set of Calculation or Design Brief?
- *[D.DE.XX]* Is the concrete cover defined based on the expected environmental aggressivity such as salinity, moisture, chlorides etc.?
- *[D.DE.XX]* Is the concrete water/cement ratio well defined for the expected environment?
- *[D.DE.XX]* Are drainage systems or minimum surface slope implemented to prevent water accumulation over the structure?
- *[D.EX.XX]* Has the design concrete water/cement ratio maintained during the execution according to the Concrete Technical Specifications?
- *[D.MA.XX]* Has water infiltration been observed during the lifespan of the bridge?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non-existent information to apply

SCORING REFERENCE SYSTEM

Related image	Score
	**0**
	**50**
	**100**

Exposure to Chlorides

Evaluation of the Shallow Cause (Primary Inquiries)

The sea water contains high concentrations of chlorides. If the porous concrete is permeable, the sea water in the form of moisture will enter into the concrete from the porous surface. Chlorides will react with the concrete and will reduce the alkalinity of concrete. Thus, the outside moisture in coastal areas also results in steel corrosion.

S.NV. Is the structure within 50km of the shoreline?	
0	The structure is inland far from the coast (50+ km)
25	-
50	The structure is near the coast (20-50km)
75	-
100	The structure is over the sea (20- km)
NO DATA	-
NON APPLICABLE	-

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

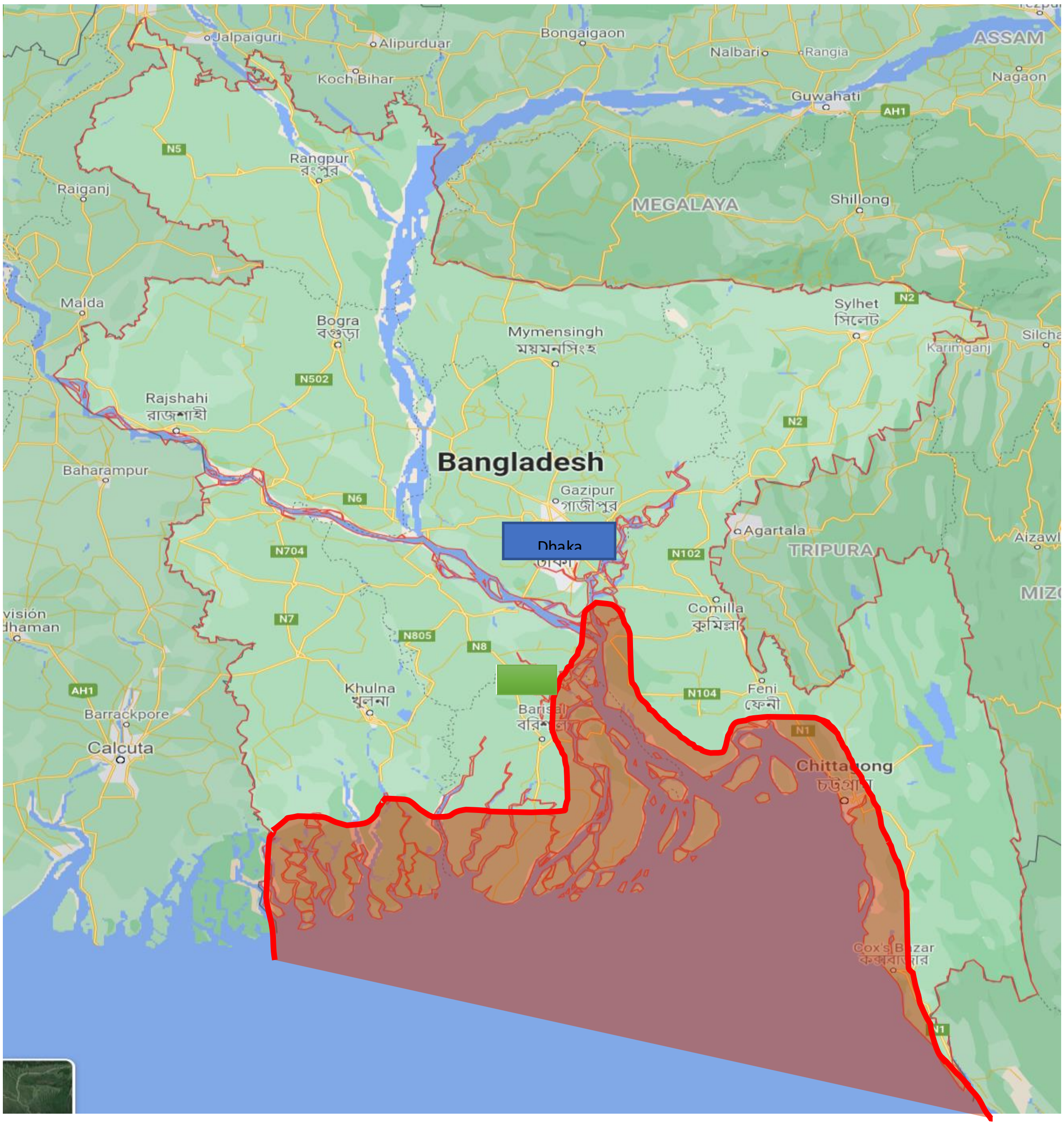
Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.DE.XX]* Is the concrete exposure category properly defined?
- *[D.DE.XX]* Is the concrete cover designed for the expected chloride intrusion?
- *[D.DE.XX]* Is the concrete water/cement ratio well defined for the expected exposure?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Related Image

Red zone: Evaluate from 50-100 if the structure is crossing sea water (100) or 20km+ (50)

Fire Exposure

Evaluation of the Shallow Cause (Primary Inquiries)

Fire reduces concrete and steel resistance when high temperatures (above 250ºC in the case of steel, 350ºC in the case of concrete) are extended in time. Besides, the non-linear thermal gradient produces different dilatation in concrete and steel, leading to loss of adhesion, spalling and cracking.

S.NV.05 Has the element suffered severe fire exposure resulting in temperature grading, leading to concrete spalling and ultimately to rebar corrosion?	
0	No signs nor reports of fire.
25	-
50	Signs or reports of mild and local fires, extinguished briefly after.
75	-
100	Signs or reports of strong and generalised fires near the structure
NO DATA	The element cannot be inspected.
NON APPLICABLE	The element is underwater.

o Cracking

Cracking phenomena definition

Cracks in concrete are breaks that generally appear on the surface of the concrete, due to the existence of tensions higher than its resistance capacity. When the crack crosses from side to side the thickness of a piece, it becomes a fissure.

From the various affections cracking can induce in concrete structures, spalling and corrosion can be highlighted. Also, cracking can be a useful indicator by its form, width and trajectory of damages or pathologies in concrete, such as an incipient structural failure or excessive deformations.

Briefly, cracking can be classified in:

- Cracks parallel to the direction of stress. They are produced by compressive stress. They are very dangerous, especially in columns because they "do not warn", since they are the result of an exhaustion of the load capacity of the material, and collapse can occur at any time.
- Cracks normal to the direction of stress. Indicative of tensile stress.
- Vertical cracks in the center of a beam span. In sections of maximum bending moments, they originate in bending stresses and are generally due to insufficient reinforcement.
- Horizontal or 45º cracks in beams. These are due to shear stresses and are caused by insufficient concrete sections in the supports, and/or insufficient reinforcement sections in stirrups and in bent irons in the supports.
- Cracks surrounding the concrete member. With a tendency to follow lines at 45º, they are due to torsional stresses and denote insufficient reinforcement to counteract them.
- Thermal cracks at the top of the beams. Following the line of the stirrups. It is due to the heating of the irons by the sun, which causes the mixture to lose moisture in the area of contact with the irons.
- Hydraulic shrinkage cracks. Occurring in slabs that are not very thick and of uniform thickness due to rapid surface drying relative to the mass by the action of the sun, relative humidity, and especially wind, or by the combination of both, these cracks appear on the surface in a meandering form, randomly located and oriented in any direction.

Some examples for identifying cracking can be seen below:

The common shallow causes of cracking in concrete structures are:

- Mechanical cause (ME)
    - Structural overload
    - Temperature and shrinkage cracking

Structural overload

Evaluation of the Shallow Cause (Primary Inquiries)

Cracking caused by structural overload is usually presented mid-span due to the bending moment and near the supports forming 45 degrees angle due to the shear stresses.

If the crack widths are less than 0.3 mm it can be assumed that the stresses are not very high and no action should be taken, however, it is recommended that the crack be monitored for verification at the next inspection. If the crack width is between 0.3 and 0.6 mm, the stress may be high but is assumed to be non-hazardous. When there is a crack width greater than 0.6 mm indicates that the stresses are high and that there may be a problem with regard to the load carrying capacity.

S.MC.XX What width do the cracks have?	
0	There is no cracking or the width is less than 0.3mm
25	-
50	The cracks have a width between 0.3 to 0.6mm
75	-
100	The cracks have a width more than 0.6mm
NO DATA	The width of the cracks cannot be estimated or measured
NON APPLICABLE	Visibly the cracking is occurring due to thermal expansion or shrinkage

Note: Please refer to 'Image Clarification' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.XX]* Do the structure's design and construction requirements consistent with the approved LGED Design Standards (please refer to Guidance Material for LGED Design Standards list)?
- *[D.DE.XX]* Does the structure have a structural calculation (internal efforts) for all its components)?
- *[D.DE.XX]* Does the design have a crack control calculation or justification?
- *[D.DE.XX]* Does the developed numerical model for the analysis of the infrastructure captures the expected behaviour?
- *[D.DE.XX]* Are the Structural Drawings clear/legible and do not provide any contradictory information?
- *[D.MA.XX]* Have the construction materials been procured, stored, and handled as per the Material Technical Specification document?
- *[D.MA.XX]* Are certificates for each of the construction materials consistent with the Material Technical Specification document?
- *[D.EX.XX]* Has the concrete been placed appropriately; such as ensuring slump value, appropriate formwork rigidity and cleanness, compliance to vibrations limits, and curing process ?
- Has the curing process, prior to any preliminary loading, last for 27 days (+/- 2 days)?

- *[D.OP.XX]* Has the structure NOT suffered from loads exceeding the Design Load during its construction and operational period?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Applicable from previous questions

SCORING REFERENCE SYSTEM

Related image	Score
	**0**
	**100**

Temperature and shrinkage cracking

Evaluation of the Shallow Cause (Primary Inquiries)

This type of cracking is usually encountered in the sun-exposed surface of the concrete. It does not present a danger to the concrete structure but it can contribute to an acceleration of the aging of the structure. Among its characteristics to differentiate it from the previous cracking are its location, superficial; and the randomly apparent trajectories of the cracks.

S.NV.XX Has the structure thermal/shrinkage cracking?	
0	There is no sign of cracking in the top surface of the structure
25	-
50	There are some shrinkage cracks patterns appearing randomly or some thermal cracks
75	-
100	There are thermal/shrinkage cracking all over the surface of the deck.
NO DATA	The surface of the concrete has not been inspected
NON APPLICABLE	-

Note: Please refer to ‘Image Clarification’ section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.DE.XX]* Does the structure allow thermal expansion, using thermal joints or sliding bearings?
- *[D.DE.XX]* Does the design have a thermal/shrinkage calculation?
- *[D.DE.XX]* Are the Structural Drawings clear/legible and do not provide any contradictory information?
- *[D.MA.XX]* Has the concrete been placed appropriately; such as ensuring slump value, appropriate formwork rigidity and cleanness, and compliance to vibrations limits?
- *[D.EX.XX]* Has the concrete curing process been followed according to the Material Technical Specification document?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non existing from previous stages

SCORING REFERENCE SYSTEM

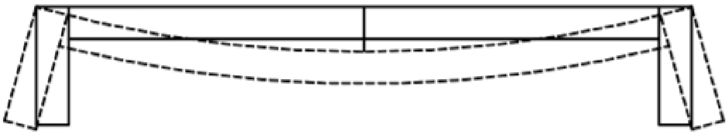
Related image	Score
	**0**
	**100**

○ Deformations

Deformations phenomena definition

The state of excessive deformation of the concrete structure affects the normal functioning of the structure, preventing the user to feel comfortable in the normal use of the structure and it can lead to the worst states of the structure. By definition, it does not put at risk the structural capacity of the structure and it is ligated to the serviceability limit state.

Some examples for properly identifying excessive deformations can be seen below:



The common shallow causes of deformations are:

- Mechanical cause (ME)
    - Deck slab capacity
    - Disproportion of the deck slab geometry

Deck Slab Capacity

Evaluation of the Shallow Cause (Primary Inquiries)

In bridges, the slab composes one of the elements of the structure, and its fundamental mission is to redistribute the efforts that are being applied on the upper surface to the beams, struts or the abutment. If not properly designed the necessary reinforcement or thickness of the slab, it can lead to the slab being locally broken or deforming excessively in mid-span.

S.MC.XX Is the deck slab visibly deformed (larger than L/300)	
0	The slab does not appear to be deformed, nor broken or less deformed than L (span length)/300.
25	-
50	-
75	-
100	The condition above is violated
NO DATA	The deformation of the slab cannot be measured
NON APPLICABLE	The element has no concrete slab

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.DE.XX]* Does the slab have adequate reinforcement to carry the resultant bending moment demand in both directions, independently?
- *[D.DE.XX]* Does the slab have adequate reinforcement to carry the resultant shear demand in both directions, independently?
- *[D.DE.XX]* Does the reinforcement in either direction qualify the 'Temperature and Shrinkage Criteria'? i.e A_s>A_{temp}
- *[D.DE.XX]* Does the slab have enough reinforcement to resist the local punching shear of the vehicle wheels?
- *[D.DE.XX]* Does the deck slab comply with minimum reinforcement criteria, in both directions?
- *[D.EX.XX]* Are the rebar/reinforcement size and spacing consistent with the Design Drawings?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Related image	Score
	0
	100

Disproportion of the deck slab geometry

Evaluation of the Shallow Cause (Primary Inquiries)

The other major cause of the deformations on the superstructure can be that the elements are distributed non proportionally. I.e., to prevent excessive deformations in the transverse section of the slab if the abutments are too separated, struts may be placed. On the contrary, we can find that another beam is needed in order to ensure the A/B proportion, explained below.

S.MC.XX Is the superstructure proportioned?	
0	The slab A/B length-width or width-length proportion between the supports of the slabs is inferior to 1.5
25	-
50	-
75	-
100	The slab A/B length-width or width-length proportion between the supports of the slabs is superior to 1.5
NO DATA	The deformation cannot be measured
NON APPLICABLE	The element has no slab-beam interaction

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

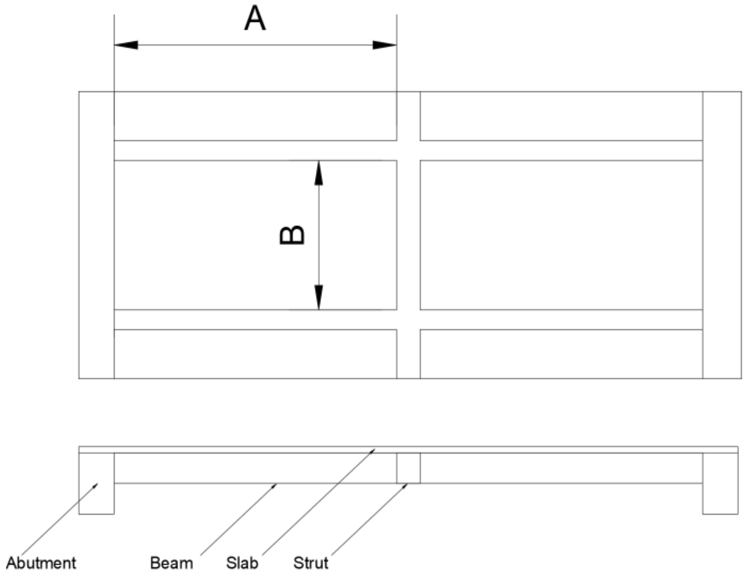
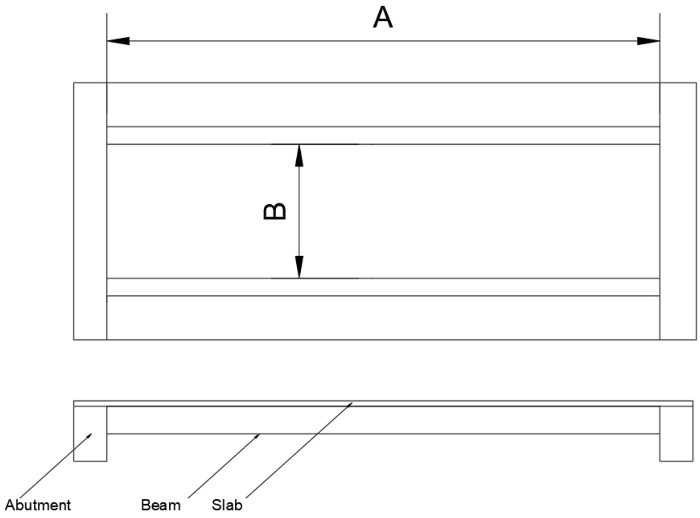
Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.DE.XX]* Does the slab thickness meet the "rule of thumb" of Thickness>Length/16 for simply-supported slabs and Thickness>Length/25 to truss-based bridge?
- *[D.DE.XX]* Has the deck slab enough transverse beams (diaphragms) to ensure A/B proportion less than 1.5?
- *[D.DE.XX]* Does the slab have adequate reinforcement to carry the resultant moment and shear demand in both directions, independently?
- *[D.DE.XX]* Is the deck slab less deformed than L/300 (L is the larger of A and B)?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Related image	Score
 A/B<1.5	**0**
 A/B>1.5	**100**

○ Honeycombs

Honeycombs phenomena definition

In concrete structures, honeycombs are defects on the surface of the concrete, with voids and hollow spaces or cavities, rougher than the overall surface of the concrete and often the aggregates can be visible. This imperfection is the result of the incomplete filling of the concrete against the formwork. Some examples for properly identifying honeycombs can be seen below:

The common shallow causes of honeycombs are:

- Mechanical causes (ME)
    - Reinforcement General Arrangement
    - Concrete Definition
    - Concrete Pouring Process

Reinforcement General Arrangement

Evaluation of the Shallow Cause (Primary Inquiries)

Following the standards of rebar calculation and execution, the rebar spacing has to be sufficient in order for the concrete mix to fill the gaps between the rebars and the formwork and to let pass the mix between the rebars, as well as to permit the proper vibration of the concrete.

S.MC.XX Are the rebars properly spaced	
0	Separation between the rebars is more than the minimum of: (1.5*rebar diameter; 20mm; 5mm+diameter of the aggregate)
25	-
50	-
75	-
100	The separation is less than the calculated value above
NO DATA	The separation cannot be measured
NON APPLICABLE	The element has no rebars

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

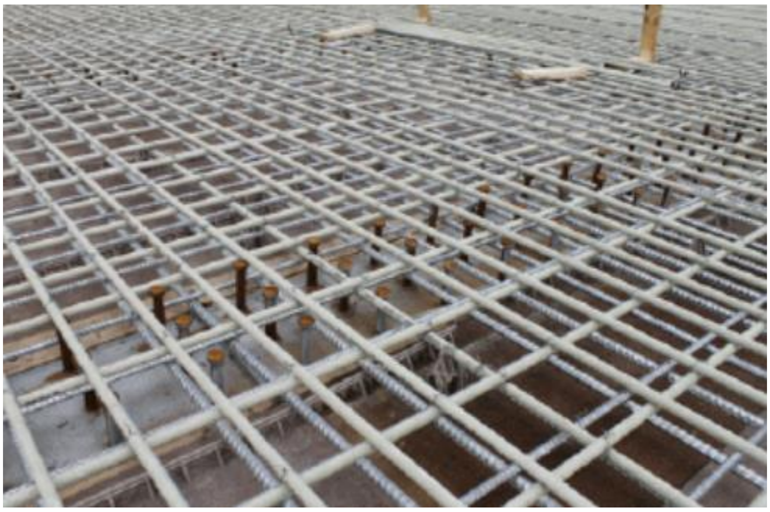
Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.DE.XX]* Is the minimum rebar spacing properly defined in the Design Drawings?
- *[D.DE.XX]* Is the minimum mechanical and geometrical cover defined in the design and in the Design Drawings?
- *[D.EX.XX]* Is the minimum rebar spacing properly executed (i.e: rebar and cover spacers) on site as per the Design Drawings?
- *[D.EX.XX]* Is the minimum mechanical and geometrical cover executed on site as per the Design Drawings?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Related image	Score
	**0**
	**100**

Concrete Definition

Evaluation of the Shallow Cause (Primary Inquiries)

The specifications of the concrete properties have a direct effect on the apparition of pathologies. Those parameters which drive the possible apparition of honeycombs are the water/cement ratio, the amount of aggregates per cubic meter of cement and the size of those aggregates.

S.MC.xx Are the concrete mechanical properties consistent with the Concrete Technical Specification?	
0	The water/cement ratio, amount and size of aggregate are correct, defined using standards and executed in those proportions.
25	-
50	-
75	-
100	The water/cement ratio, amount or size of aggregate are incorrect as per standards.
NO DATA	There has no traceability of the properties of the executed concrete
NON APPLICABLE	-

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.DE.XX]* Is the aggregate grading (size of the aggregate) properly defined in the Concrete Technical Specification (Design Stage)?
- *[D.DE.XX]* Is the amount of the aggregate unit weight, void ratio, absorption and surface moisture properly defined in the Concrete Technical Specification (Design Stage)?
- *[D.DE.XX]* Is the water cement ratio properly defined in the Concrete Technical Specification (Design Stage)?

0	25	50	75	100	NO DATA	NON APPLICABLE
None of the time	Rarely	Some of the time	Often	All of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Concrete Pouring Process

Evaluation of the Shallow Cause (Primary Inquiries)

The process of execution of the concrete structures is as crucial as the definition of the concrete mix properties. If unattended, the concrete cannot fill properly the spaces between the formworks, the aggregates could decant to the bottom of the structure leaving a cement-water mix in the upper part of the structure, affecting the capacity of the structure, causing honeycombs in the bottom, etc.

S.MC.XX Has the concrete element been properly executed?	
0	No signs of negligence during the execution of the structure.
25	-
50	-
75	-
100	There has not been control on how the concrete mix was being executed and there were no records of the decisions made
NO DATA	The element cannot be inspected.
NON APPLICABLE	-

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.EX.XX]* Does the aggregate grading used in construction is consistent with the requirements set in the Concrete Technical Specification (Design Stage)?
- *[D.EX.XX]* Is the amount of the aggregate per cubic meter properly executed (Construction Certificates/Reports)?
- *[D.EX.XX]* Is the amount of water per cubic meter of cement properly executed (Construction Certificates/Reports)?
- *[D.EX.XX]* Has the slump test been performed for each concrete batch?
- *[D.EX.XX]* Has the concrete been placed within the suggested time frame without "hampering" workability?
- *[D.EX.XX]* Has the concrete been always poured from less than 1m high?
- *[D.EX.XX]* Has the concrete element been vibrated according to LGED Standard document or Material Technical Specification document?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

○ Lack of continuity

Lack of continuity phenomena definition

When the anchorage length between the reinforcement of two columns or between a column and a slab is short, the connection between the two elements does not have the required continuity and adhesion. The most common zones where the lack of continuity can be seen are in the interactions between elements, i.e. the connection between the foundations and the piles, or slabs-beams connections, etc.

In the case of beam-pier connections, this can lead to cracking when the reinforcement slides in the concrete. If the beam is not able to support the new stress distribution, it may break, leading to structural failures.

Some examples for properly identifying lack of continuity in concrete structures can be seen below:

The common shallow causes of the lack of continuity are:

- Mechanical (MC)
  - Poor connection design between key structural elements
  - Poor execution (Planning and/or Procurement Stages)

Poor connection design between key structural elements

Evaluation of the Shallow Cause (Primary Inquiries)

Structural detailing is one of the most important parts of the design process, despite being one of the last documents and drawings to be generated. The key aspects to having a well detailed connection between the elements is the reinforcement detailing and interaction between the elements. For example, if a foundation-pile detail is going to be generated, the designer must dispose of standby reinforcements in the foundation to receive the posterior reinforcement and concreting phase of the piles. More information regarding this matter can be found in the Failure Analysis Report.

S.MC.XX Is there reinforcement connecting the two concrete elements in the design?	
0	There is reinforcement in the design with sufficient anchorage length
25	-
50	-
75	-
100	There is reinforcement connecting the two elements but does not have sufficient anchorage length according to standards or reinforcement is missing.
NO DATA	The drawings cannot be inspected
NON APPLICABLE	The two elements have no rigid connection between them (a bearing is separating)

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

2.2. Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.01]* Are Design Standards properly identified at the Design Stage?
- *[D.DE.XX]* Do the connection reinforcement have enough anchorage capacity to develop the reinforcement full strength?
- *[D.DE.XX]* Is the reinforcement detailing (length, diameter, position, mechanical and geometrical cover) clearly defined in the Structural Drawings and do not provide any contradictory information?
- *[D.EX.XX]* Has the structure been executed following the Design Drawings?

0	**25**	**50**	**75**	**100**	**NO DATA**	**NON APPLICABLE**
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non existing from previous stages

SCORING REFERENCE SYSTEM

Poor execution (Planning and/or Procurement Stages)

Evaluation of the Shallow Cause (Primary Inquiries)

Concreting phasing planning and forecast is important to ensure the connection between different concreting times. If unattended the stops, the new concrete can have difficulties adhering to the curated or more rigid concrete, leading to a weak spot in which the shear forces can actually break the concrete element. In the execution phase, there has to be enough forecast to assume the application of concrete bonding between the elements and placement of shear reinforcements if necessary, according to standards.

Another source of errors in the construction phase is the coordination between the different construction works. The figure of the coordinator must take into account the timing between the finalization of the foundation concreting and the pile concreting, for example. If not possible, then measures like the described in the first paragraph have to be applied.

	S.EX. Has the concreting of the elements been stopped during execution?
0	No/Yes but they have been planned and the connection between the two different concretes have been assured via reinforcement and/or concrete bonding.
25	-
50	Yes, but they have been planned and the connection between the two different concretes have been assured ONLY via concrete bonding.
75	-
100	Stops have NOT been planned and the connection between the two different concretes is NOT ensured/There is no information of the concreting of the element
NO DATA	-
NON APPLICABLE	The element is prefabricated

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.EX.XX]* Has the concreting strategy been planned before the construction?
- *[D.EX.XX]* If uncontrolled stops happened during concreting, have mitigation measures been taken to prevent the concrete discontinuity?
- *[D.EX.XX]* Is the poor execution resulting from the lack of coordination between several contractors/construction works onsite?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non existing from previous stages

SCORING REFERENCE SYSTEM

○ Movement joint malfunctioning

Movement joint malfunctioning phenomena definition

Joints are deformable devices capable of absorbing relative movements of the deck, ensuring the transit of vehicles across discontinuities between the different structural sections of a bridge.

At the moment the joint starts malfunctioning, the efforts, vibrations and deformations the joint is supposed to absorb are being transmitted to the next element in the bridge, causing deformations, cracking and can lead to failure in other parts, such the bearings. Locally, the lack of the joint normal functioning can cause deterioration of the joint-concrete union and ultimately the disaggregation of the concrete near the joint due to the repetitive impact of vehicular loads.

Some examples can be seen below:

The common shallow causes of joint malfunction are:

- Mechanical cause (ME)
    - Joint Deterioration
- Environmental cause (EN)
    - Clogged joint

Joint Deterioration

Evaluation of the Shallow Cause (Primary Inquiries)

Malfunction can be caused by deficiencies in its structural design, which means that the component does not have the capacity to absorb the deformations between the approach area and the deck. This happens when the type of joint selected is not suitable, which depends on the type of bridge, its typology and length, or when the joints are not properly anchored to the bridge components. This problem is reflected in the deterioration and detachment of its parts due to inadequate shaping combined with increased impact.

The inadequate design of the area around the joints generates problems of water puddling and later affecting the components of this device, generates infiltration problems that accelerate the degradation and deterioration of the components of the bridge.

S.MC.XX Has the joint deformed excessively under design load or has been severely deteriorated	
0	There is no sign of deformation or deterioration
25	-
50	Deformation can be seen in the metallic parts of the joint and in the nearly concrete there are signs of disaggregation
75	-
100	Parts of the joints are detached from the concrete and the concrete near the joint is heavily deteriorated
NO DATA	The deformation cannot be measured or the joint is not visible
NON APPLICABLE	There is no joint in the bridge

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.01]* Are Design Standards properly identified at the Design Stage?
- *[D.DE.XX]* Has the thermal expansion/contraction calculation compliant with the Design Standards?
- *[D.EX.XX]* Has the mechanical device been designed following seismic reinforcement guidelines, when applicable?
- *[D.MN.xx]* Is the mechanical device age less than the specified Device Design Life (typically 15-20 years design life)?
- *[D.EX.XX]* Does the constructed joint match the specifications from the design?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non existing from previous stages

SCORING REFERENCE SYSTEM

Related image	Score
	**0**
	**100**

Clogged Joint

Evaluation of the Shallow Cause (Primary Inquiries)

One of the problems with joints is its clogging with foreign matter that affects the horizontal and vertical movements that the joint must withstand. This can lead to deterioration of the seal, possible passage of water through the joint and effect on the durability of supports and abutments.
Deterioration can also be caused by corrosion on plates that are part of the steel joint types, inadequate welded connection between the angles, failure of the anchorages that join the components of the joint device to the parts of the bridge. components of the joint device to adjacent parts of the bridge (slab, diaphragm, etc.), inadequate construction of the edge protection due to lack of adhesion and poor quality of the concrete, increased of the expected legal loads or fall of inadmissible chemical agents affecting mastic used for installation.

S.NV.XX Has clog material/debris been accumulated within the joint expansion zone area?	
0	The two faces of the joint are clearly separated or they are properly sealed against external matter
25	-
50	Some parts of the joint have matter/soil/vegetation between them but it still has its majority clean or sealed.
75	-
100	The joint is absolutely clogged and its functioning does not seem possible
NO DATA	-
NON APPLICABLE	There is no joint in the bridge

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.MN.xx]* Has the joint Seal been damaged?
- *[D.MN.xx]* Has the last inspection of the mechanical device been done less than 2 years ago?
- *[D.MN.xx]* Has the last maintenance of the mechanical device been done less than 5 years ago?
- *[D.MN.xx]* Is the mechanical device age less than the specified Device Design Life (typically 15-20 years design life)?
- *[D.MN.xx]* Has the element not been exposed or is not exposed to marine ambient

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non-existent information to apply or applicable from previous questions

SCORING REFERENCE SYSTEM

Related image	Score
	**0**
	**100**

○ Scour and erosion

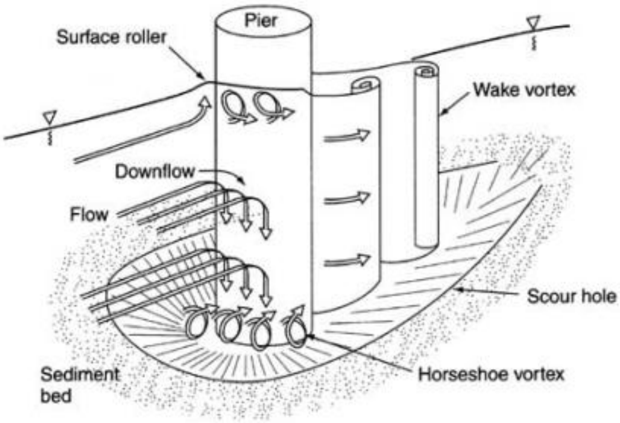
Scour and erosion phenomena definition

Scour is the result of the erosive action of the flow of water over rivers, which uproots and carries material from the bottom of the bed and lateral banks. A distinction should be made between general and local erosion. The former is due to the dragging of solid particles from the riverbed produced by the passage of water at a speed greater than the critical velocity (function of multiple variables), which entails the dragging of these particles.

Local erosion occurs in the presence of obstacles in the channels such as abutments and piles, together with their respective foundations. When water collides head-on and at high speed against these obstacles, it produces a flow of descending particles which, on colliding with the bottom of the channel, produce a series of vortices that violently drag the material from the bottom of the foundation, producing scour pits, generally of large dimensions, which can affect the foundation of the element, putting the stability of the element and thus of the structure at risk.

The greatest damage due to scour occurs during floods, periods in which the speed of the water current is at its maximum, causing the greatest damage to the foundations of piles and abutments.

Some images of scour and erosion affecting abutments, piles and piers can be seen below:



Scour and erosion graphic definition and evolution

The shallow cause of scour and erosion is:

- Environmental (S.NV)
  - Water Erosion

Water Erosion

Evaluation of the Shallow Cause (Primary Inquiries)

Water is the most common component of the origin and aggravation of the scour-erosion process.

S.NV.XX Has the water eroded the soil material under the foundations/abutment/piers?	
0	There is no sign of material transportation near the foundations and the protections remain intact
25	-
50	The pier/abutment stability needs maintenance duties, as the foundation is starting to lose contact with the soil.
75	-
100	The pier/abutment stability is heavily compromised, landslides occur in the embankment's slopes near the abutment and/or the piers are unsubmerged.
NO DATA	The piers/abutment foundations cannot be inspected
NON APPLICABLE	There is no pier or abutment

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.xx]* Was there any hydraulic study done before the Design Stage and taken into account into the design?
- *[D.DE.xx]* Are the pier/piles protections defined in the design?
- *[D.EX.xx] Are the pier/piles protections executed as per the design?*
- *[D.DE.xx] Is the abutment protection defined in the design?*
- *[D.EX.xx] Is the abutment protection executed as per the design?*
- *[D.MN.xx] Has the last inspection of the pier/piles/abutment been taken in less than two (2) years?*

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Related Image	Image Score
	**0**
	**50**
	**100**

○ Spalling

Spalling phenomena definition

Concrete spalling is a defect that appears in a hardened concrete structure or blocks situated in colder climates, where the concrete is slowly broken down into small flakes known as spalls from a larger solidified concrete body. Spalling is normally seen in a concrete slab or a layer of concrete in locations that have colder climates and experience the constant destructive forces of cyclic freezing and thawing (freeze-thaw cycle). The situation is exacerbated when salt or deicing chemicals are used on the concrete surface.

The common shallow causes of spalling are:

- Mechanical (ME)
    - Corrosion
    - Over compression
    - Impacts

Corrosion

Evaluation of the Shallow Cause (Primary Inquiries)

Corrosion can be produced by other pathologies or produce other pathologies, like Spalling or Crackings. It is not always easy to determine which pathology was produced first. According to that, common deep causes for both pathologies will be explored. Please have in mind this concomitance of pathologies and be aware of any hint about which the primigenius pathology might be in order to report feedback for this toolkit.

S.PT.02 Has corrosion of rebars been observed?	
0	No signs of corrosion to be seen
25	There are slight signs of corrosion, but in punctual places and not connected.
50	Corrosion begins to spread, stains radius are 1 or 2 cm but still not connected, or multiple punctual stains appear.
75	Corrosion generalizes, stains radius are 5 to 10 cm and connections among stains begin to appear, or punctual stains are generalized.
100	Corrosion is severe and affects the whole concrete element. Delamination of steel might be seen
NO DATA	Reinforced element cannot be inspected
NON APPLICABLE	There is no metal to be corroded in the concrete element

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.DE.XX]* Are there calculations/estimations of the width of the expected cracks in the reinforced concrete?
- *[D.DE.XX]* Is the aggressivity of the environment such as moisture, salinity, chloride and others, properly addressed and defined at Design Stage?
- *[D.DE.XX]* Is the concrete mechanical cover designed for the expected environmental aggressivity?
- *[D.DE.XX]* Is the concrete water/cement ratio well defined for the expected environment?
- *[D.DE.XX]* Are there drainage systems to prevent water accumulation over the structure?
- *[D.EX.XX]* Has the concrete water/cement ratio been controlled during the execution according to the Material Specification document?
- *[D.MA.XX]* Has moisture infiltration/penetration in the concrete elements been observed during the lifespan of the bridge?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Corrosion Related Images	Score
	**0**
	**50**
	**100**

Over compression

Evaluation of the Shallow Cause (Primary Inquiries)

Over compression might cause fractures in the concrete and buckling. As a consequence of it, concrete might begin to spall. It is not a common phenomenon and their reasons used to be related with an inadequate design rather than an unexpected overload.

S.MC.01 Is there signs of the pathology being produced in an over-compressed region	
0	The element is placed in a region that experiments only with tension efforts.
25	The element works mainly under bending and shear efforts (i.e. beams and slabs) and signs of over compression are not evident.
50	The element works mainly under compression efforts (i.e. columns) but signs of over compression are not evident.
75	(No use of this answer)
100	The element works mainly under compression efforts (i.e. columns) and signs of over compression are evident (compression crackings, buckling, etc).
NO DATA	The element works mainly under compression efforts (i.e. columns) and signs of over compression are evident (compression crackings, buckling, etc).
NON APPLICABLE	The element is not structural (i.e. parapets, fences, etc).

Note: Please refer to ‘Scoring Reference System’ section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.01]* Are Design Standards properly identified for compression elements at the Design Stage?
- *[D.DE.XX]* Are compressed elements compliant with the Design Standards?
- *[D.MA.XX]* Have the construction materials been procured, stored, and handled as per the Material Technical Specification document?
- *[D.EX.XX]* Has the structure been executed following the Design Drawings?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Corrosion Related Images	Score
	**0**
	**50**
	**100**

Impacts

Evaluation of the Shallow Cause (Primary Inquiries)

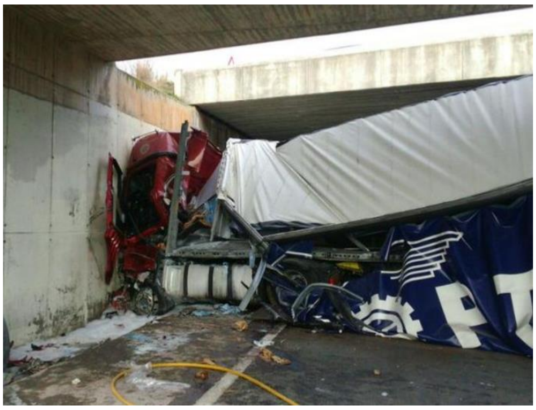
Impacts may happen both in the Execution or in the Operation and Maintenance phases. Even when a structure has been designed to resist some level of impacts, these can produce undesired effects at local level, like Spalling.

S.MC.02 HAS THE ELEMENT SUFFERED HIGH IMPACTS DURING COMMISSIONING OR OPERATION?	
0	There are no signs nor reports of impacts around the spalling emplacement, and impacts are improbable (the element region is not subject to potential impacts as might be the case of columns, parapets or precast pieces when commissioned).
25	There are no signs nor reports of impacts around the spalling emplacement but impacts are possible (i.e. columns or precast pieces).
50	There are no signs nor reports of impacts around the spalling emplacement but impacts are probable (i.e. parapets, movement joints).
75	*(No use of this answer).*
100	Sign or reports of impacts are evident (i.e. witnesses' testimonials, braking marks, etc).
NO DATA	The element cannot be inspected.
NON APPLICABLE	Question S.MC.02 related to Spalling is always applicable.

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Corrosion Related Images	Score
	**0**
	**50**
	**100**

○ Structural failure

Structural failure phenomena definition

The structural failure is the inability of the structure to continue its functioning due to a loss of stability of the components of the structure or the structure as a whole. The structure is unsafe for operation. It comprehends situations as structural collapse, fracture of the components, overturning of the structure or detachment of the parts of the structure.

Some examples for properly identifying structural failure can be seen below:

The common shallow causes of structural failure are:

Mechanical cause (ME)

- Structural Collapse
- Exceedance of Structural Capacity

Structural Collapse

Evaluation of the Shallow Cause (Primary Inquiries)

The instability of the bridge usually implicates the collapse of the bridge as a whole or parts of the concrete structure. Moreover, the instability of the elements can have an environmental cause, water or seismic. As it can be seen, the environmental causes are accidental and as they are not the frequent operation cases, it could have been overlooked.

S.NV.XX Has the structure collapsed (or partially collapsed) due to river flooding or earthquake	
0	There is no report of heavy flooding or earthquakes at the moment of the structural failure
25	-
50	-
75	-
100	There are reports indicating heavy flooding or earthquakes at the moment of the structural failure
NO DATA	-
NON APPLICABLE	-

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.xx]* Was there any hydraulic study done before the Design Stage?
- *[D.DE.XX]* Has the hydraulic study been considered in the structural design as a flooding load case?
- *[D.DE.XX]* Does the structural design include a seismic load case?
- *[D.DE.XX]* Is the considered seismic load case consistent with current Design Standards?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non-existent information to apply or applicable from previous questions

SCORING REFERENCE SYSTEM

Related image	Score
	**0**
	**100**

Exceedance of Structural Capacity

Evaluation of the Shallow Cause (Primary Inquiries)

When the structural capacity of the bridge is surpassed, the structural failure can occur. It can be evaluated in relation to the part of the structure where the failure has originated. Attending this, it can be differentiated in two, failure near the supports due to shear effort and failure in mid span due to bending moment.

Structural failure in case of the bending moment can be assessed before the collapse of the structure due to the excessive deformation of the span and the shear effort failure starts with cracking at 45 degrees from the supports and it can reach structural collapse without seeing excessive deformations in the elements.

S.MC.XX Has the structural capacity of the elements been exceeded	
0	There is no sign of deformation mid span nor cracking 45 degrees from the supports
25	-
50	-
75	-
100	The span is near the collapse with excessive deformations mid span or the cracks exceed 5mm forming 45 degrees from the support
NO DATA	The deformation or crackings cannot be measured
NON APPLICABLE	

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.xx]* Are Design Loads properly defined at Design Stage?
- *[D.DE.XX]* Has the load exceeded the Design Load?
- *[D.DE.XX]* Does the element have enough bending moment reinforcement in all directions ?
- *[D.DE.XX]* Does the element have adequate shear reinforcement near the abutments and diaphragms?
- *[D.DE.XX]* Does the element have adequate torsional shear reinforcement near the abutments and diaphragms?
- *[D.DE.XX]* Is the reinforcement detailing (length, diameter, position, mechanical and geometrical cover) clearly defined in the Structural Drawings and do not provide any contradictory information?
- *[D.EX.XX]* Has the structure been executed following the Design Drawings?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non existing from previous stages

SCORING REFERENCE SYSTEM

Related image	Score
	**0**
	**100**

2. GUIDANCE MATERIAL: EMBANKMENT PATHOLOGY

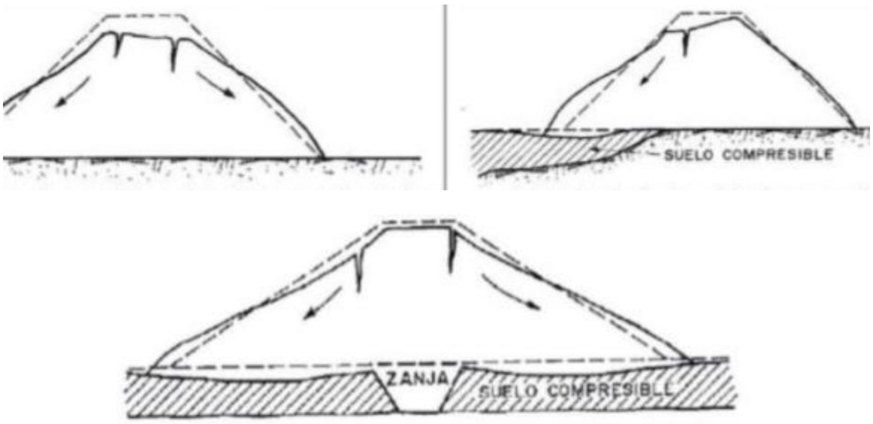
○ Excessive deformations

Excessive deformations phenomena definition

Soil deformations can be divided relatively to the movement of the embankment. If the deformation is in the vertical direction is known as settlement, while deformations in the horizontal direction can be embankment instability.

The largest settlements on the embankment usually occur in soils of organic origin or lake deposits, mainly clayey. Due precautions must be taken when laying foundations on soft soils, calculating short and long term settlements. An embankment, even if it is supported on completely firm ground, can also deform. If the slope angle is excessive, deformations can cause cracking at the crest.

Compacting the materials with the different techniques available plays a critical role, or replacing the materials with another of better quality.



The shallow causes of the excessive deformations of the embankments are:

- Mechanical cause (ME)
    - Improper soil compaction
    - Slope instability

Improper Soil Compaction

Evaluation of the Shallow Cause (Primary Inquiries)

The study of slope stability deals with ultimate state phenomena or the rupture of soil masses. The external "agent" responsible for instability is a mass force: weight and possibly seepage effects to which must be added, generally as a secondary factor, to possible external loads. The quantitative determination of risk or safety indices requires the use of techniques and models specific to Soil or Rock Mechanics.

S.MC.XX Is the excessive deformation visibly spread over the road cross section??	
0	The embankment is not deformed or is deformed near the slopes
25	
50	The embankment is partially deformed in the upper part, visibly deforming the road
75	
100	The embankment deformation is affecting all the cross section, putting at risk the trafficability of the road
NO DATA	The embankment cannot be inspected
NON APPLICABLE	There is no embankment

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.xx]* Has a Geotechnical Investigation Campaign and Interpretative Report been produced prior to the Design Stage?
- *[D.DE.XX]* Is the Geotechnical Investigation Campaign sufficiently extended (type and number of tests) to cover the project length?
- *[D.DE.XX]* Has the material of the embankment (gradation, void ratio, unit weight, moisture content etc.) been properly defined by the Geotechnical Team, consistent with the expected Design Load?
- *[D.DE.XX]* Has the Geotechnical Team defined the optimal 95% Modified Proctor Compaction Index or CBR value for the embankment material?
- *[D.DE.XX]* Has the correct construction machinery been selected to compact the embankment material ?
- *[D.EX.XX]* Is the embankment material properly drained before and during compaction?
- *[D.EX.XX]* Have the Technical Specifications been followed during execution of the compaction (layer thickness, humidity, compaction energy, …)?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Related Image	Image Score
	**0**

Slope Instability

Evaluation of the Shallow Cause (Primary Inquiries)

Soil compaction is a process by which the particles that make up the surface are agglomerated with greater insistence, achieving a reduction of the void and, thus, a much more solid and viable ground for the work to be developed. A proper soil compaction, reduces water scouring, prevents settlements and ultimately excessive deformations, affecting the road trafficability on top of the embankment.

S.MC.XX Is the excessive deformation visibly spread over the embankment slope?	
0	The embankment is not deformed near the slopes
25	
50	Cracks have started to appear in the upper part of the embankment near the slope
75	
100	Soil mobilization has occurred in the slope in the form of a sliding circle.
NO DATA	The embankment cannot be inspected
NON APPLICABLE	There is no embankment

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.xx]* Has a Geotechnical Investigation Campaign and Interpretative Report been produced prior to the Design Stage?
- *[D.PL.xx]* Has a Hydrogeological Investigation Campaign and Interpretative Report been produced prior to the Design Stage?
- *[D.DE.xx]* Does slope stability have been checked at the Design Stage?
- *[D.MA.xx]* Is the angle of friction of the constructed embankment's material less than the angle of the slope?
- *[D.DE.xx]* Has any of the Standard LGED Design for embankments (embankment material, slope value, slope protection, …) been used?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

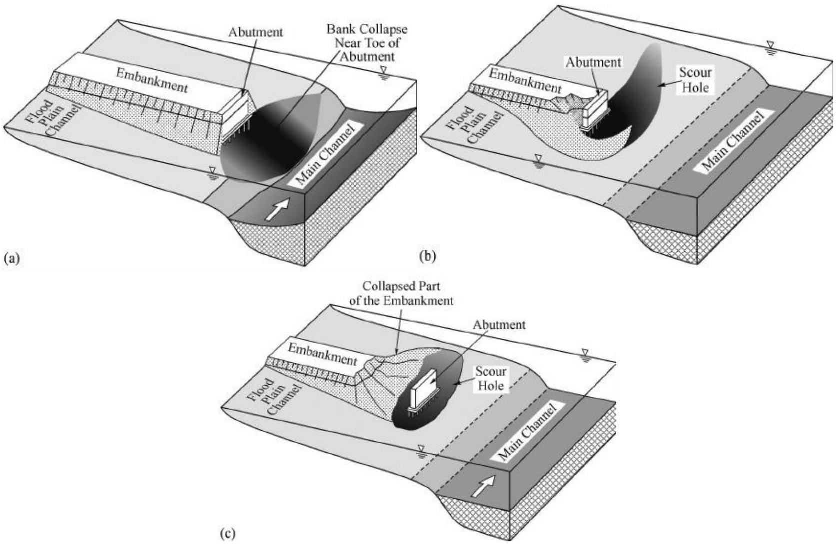
Related Image	Image Score
	**0**
	**50**

○ Scour and washout

Scour and washout phenomena definition

Scour is defined as the excavation as result of the erosive action of the water flux and washout is the process of material transport the water causes. These two phenomena are intrinsically ligated, the combined pathology starts with a washout of the material in the base of the embankments, causing scour as the stability of the embankment is compromised.

As it continues cyclically, the pavement loses support and it collapses due to the scour hole.



Scour and washout graphic definition and evolution

The shallow causes of scour and washouts of the embankments are:

- Environmental (S.NV)
    - Water erosion

Water erosion

Evaluation of the Shallow Cause (Primary Inquiries)

Water is the most common component of the origin and aggravation of the scour-washout process.

S.NV.XX Is the loss of embankment material clearly visible from the scour process?	
0	There is no sign of water in the embankment and no cracks in the top or ladder of the embankment
25	Water is present in the embankment and there are cracks in the top or ladder of the embankment
50	Water is present in the embankment and there are visible movements of the material in small landslides and cracks have appeared.
75	Material is being transported due to water and there are socavations in some parts of the embankment
100	The embankment stability is heavily compromised, landslides occur in the embankment's slopes, water is entering the socavations and it extracts the materials augmenting the size of the holes
NO DATA	The embankment cannot be inspected
NON APPLICABLE	There is no embankment

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.xx]* Has a Hydrogeological Investigation Campaign and Interpretative Report been produced prior to the Design Stage for embankments stability?
- *[D.DE.xx]* Is the embankment properly drained or protected against water erosion?
- *[D.MN.xx]* Are the embankment drainage culverts properly maintained for effective drainage and embankment protection?
- *[D.PL.xx]* Is the base/toe of the embankment far away from a water stream, pond, etc. or protected against water erosion as per LGED Embankment Standard Design?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Related Image	Image Score
	**0**
	**50**
	**100**

3.GUIDANCE MATERIAL: PAVEMENT PATHOLOGY

○ Potholes

Pothole phenomena definition

A bowl shaped of various sizes on the pavement surface. The surface has broken into small pieces by surface cracking or by localized disintegration of the mixture and the material is removed by traffic forcing underlying granular materials out of the hole increasing the depth. Typically, it stems from surface cracking. In time, traffic loads and rainfall water deteriorate a particular area producing the hole which can affect all pavement layers including the subgrade.

From both design and construction standpoint, similar information as for surface cracking should be checked. In this case, data from maintenance may be of great importance, and the lack of crack sealing or resurfacing in the operation period could be a possible cause.

The common shallow causes of potholes are:

- Mechanical cause (ME)
    - Fatigue Cracking
    - Traffic Loads
    - Type and Properties of Aggregates

- Environmental cause (EN)
    - Water sources

Fatigue Cracking

Evaluation of the Shallow Cause (Primary Inquiries)

Cracks are a common cause of pathologies, uncontrolled cracking of the road allow water seepage, washing out the lower layers of its structure, the base and subbase soil underneath the flexible pavement, leading to a local depression of the pavement, which traffic impacts can erode, causing the pavement to lose its flexibility and ultimately form a pothole.

It occurs in areas subjected to repeated traffic loading and they can be identified as a series of interconnected cracks many-sided with sharp angled pieces, usually less than 0.3m on the longest side.

S.MC.04 Are there signs of visible cracks or series of interconnected cracks on the pavement surface?	
0	There is no sign of cracking in the road
25	There are slight signs of cracking in partial areas of the road
50	Cracking occurs frequently and discur along >5m in length
75	Interconnected cracks of <3mm width and >2.5m usually appear in the road
100	Interconnected cracks of >3mm and >2.5m width appear in the road
NO DATA	There are no observations on cracks in the road
NON APPLICABLE	The road is not pavemented

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

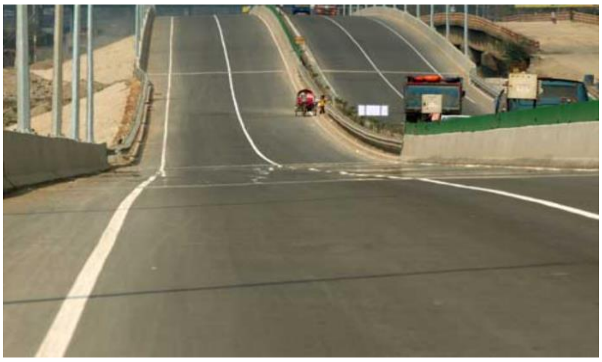
Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.01]* Are Design Standards properly identified at the Design Stage?
- *[D.DE.33]* Is the extension and compaction of the asphalt clearly defined?
- *[D.DE.XX]* Has the material of the base-subbase (gradation, void ratio, unit weight, moisture content etc.) been properly defined by the Geotechnical Team, consistent with the expected Design Load?
- *[D.DE.XX]* Has the correct construction machinery been selected to compact the embankment material ?
- *[D.OP.7]* Is the road pavement still within its expected design life, according to the Pavement Technical Specification document?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Fatigue Cracking Related Image	Image Score
	**0**
	**50**
	**100**

Traffic loads

Evaluation of the Shallow Cause (Primary Inquiries)

Flexible pavements are designed using standards and codes to determine the total thickness, materials and number of layers to resist a number of load cycles in the lifespan of the road. The initial assumptions in the design can affect radically the level of maintenance the road needs to have. A low approach to the real vehicular loads affects the lifespan of the road, leading to an increase in the fatigue of the layers and stiffness of the flexible pavement, making the road more propense to cracks, rutting and potholes.

S.MC.06 How many truck loads is the road subjected to?	
0	Heavy traffic, trucks or similar is rare (1 or less in an hour)
25	Heavy traffic, trucks or similar is ocasional (5 or less in an hour)
50	Heavy traffic, trucks or similar is moderate (5-7 in an hour)
75	Heavy traffic, trucks or similar is frequent (8-9 in an hour)
100	Heavy traffic, trucks or similar is usual (10 or more in an hour)
NO DATA	There are no observations on the traffic in peak hours
NON APPLICABLE	The road is not subjected to traffic by its conception

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.xx]* Has Traffic Studies been produced prior to the Design Stage?
- *[D.DE.XX]* Is the traffic loading calculated according to AASHTO requirements, for design consistency?
- *[D.DE.32]* Is the asphalt designed to resist the traffic design load during its design life?
- *[D.OP.xx]* Is there any evidence that traffic load exceeding the design load has occurred?
- *[D.OP.02]* Is there any evidence that significant vehicle braking forces have been transferred to the asphalt pavement?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Traffic Loads Related Images		Score
1 truck per hour		**0**
5/7 trucks per hour **or** **1 truck per 10 mins**		**50**
More than 10 trucks per hour **or** **more than 2 trucks per 10 mins**		**100**

Type and Properties of Aggregates

Evaluation of the Shallow Cause (Primary Inquiries)

Type and properties of the aggregate base, subbase and subrace will also play a critical role related to structural value and pothole formation:

S.MC.XX. Has the road a proper aggregate design following standards for the expected traffic?	
0	Matches the table in graphic clarification 100%
25	Matches the table in graphic clarification 75%
50	Matches the table in graphic clarification 50%
75	Matches the table in graphic clarification 25%
100	Matches the table in graphic clarification 0%
NO DATA	There are no observations on the traffic in peak hours or the aggregate design is not mentioned
NON APPLICABLE	The road has no aggregate

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.01]* Are Design Standards properly identified at the Design Stage?
- *[D.DE.XX]* How consistent is the surface layer thickness throughout the paved surface (asphalt edge thickness versus centreline thickness)?
- *[D.DE.XX]* Was an aggregate base used to build the roadway?
- *[D.DE.XX]* Is the aggregate mix calculated according to AASHTO and/or the Pavement Design Catalogue of LGED?
- *[D.EX.XX]* Have the Pavement Technical Specifications been followed during execution?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Related graph

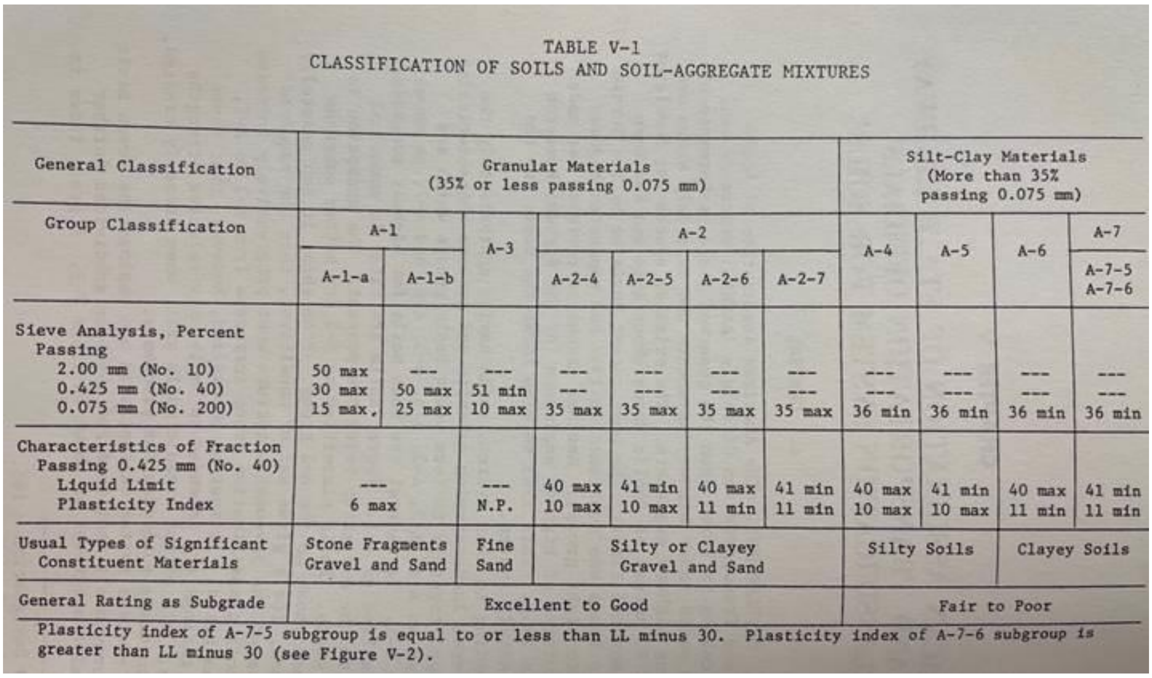


TABLE V-1
CLASSIFICATION OF SOILS AND SOIL-AGGREGATE MIXTURES

General Classification	Granular Materials (35% or less passing 0.075 mm)							Silt-Clay Materials (More than 35% passing 0.075 mm)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis, Percent Passing											
2.00 mm (No. 10)	50 max	---	---	---	---	---	---	---	---	---	---
0.425 mm (No. 40)	30 max	50 max	51 min	---	---	---	---	---	---	---	---
0.075 mm (No. 200)	15 max.	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of Fraction Passing 0.425 mm (No. 40)											
Liquid Limit	---		---	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity Index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min
Usual Types of Significant Constituent Materials	Stone Fragments Gravel and Sand		Fine Sand	Silty or Clayey Gravel and Sand				Silty Soils		Clayey Soils	
General Rating as Subgrade	Excellent to Good							Fair to Poor			

Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30 (see Figure V-2).

Water Sources

Evaluation of the Shallow Cause (Primary Inquiries)

The presence of water near the borders of the road, in the form of rivers, channels or even a pond, if uncontrolled, can lead to a washing of the top layers of the soil underneath the pavement and to a reduction of the capacity to absorb the pressure transmitted from the surface. This outcome is analogous if the road has no slopes to guide the rain water to its sides, the water accumulates above the surface and where cracks are located, it infiltrates into the top layers of the soil.

Drainage is a critical requirement that impacts structural roadway capacity and pothole formations. It can be measured on how much time it takes for the water to not be not visible on the roadway surface or near the pavement surface edge after rainfall stopped. In other words, no or very little water observed on the surface of the road or on the edge of the roadway surface layer after:

S.NV.06 How much time does it take to properly drain the surface of the road?	
0	6 hours or less
25	-
50	6 hours to 3 days
75	-
100	More than 3 days
NO DATA	There are no observations on the water
NON APPLICABLE	The road is not affected by rain/water sources

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.XX]* Is the road near a water source, like a river, channel…?
- *[D.PL.xx]* Has a Hydrological Investigation Campaign and Interpretative Report been produced prior to the Design Stage?
- *[D.DE.03]* Is the drainage system precisely and clearly calculated?
- *[D.DE.xx]* Is the base-subbase far away from a water stream, pond, etc. or protected against water erosion as per LGED Embankment Standard Design?
- *[D.MN.xx]* Are the drainage culverts properly maintained for effective drainage and embankment protection?

0	**25**	**50**	**75**	**100**	**NO DATA**	**NON APPLICABLE**
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

○ Rutting

Rutting phenomena definition

Rutting has long been a major concern for flexible asphalt pavements. It is also one of the most common permanent pavement deformations due to repetitive traffic loads, which gradually accumulate small pavement deformations that appear as longitudinal depressions in the wheel paths of roadways. Not only is rutting a concern for driving safety, but also it reduces pavement strength and the service life, increasing the difficulty of pavement maintenance as well as its cost.

The primary problem of rutting arises from excessive traffic consolidation in the upper layer of the pavement, plastic deformation due to insufficient mixture stability and also instability caused by stripping of asphalt binder below the riding surface of the pavement.

In the literature it is found that the main causes will form two different types of rutting patterns. The first is the rutting of the upper layer of the asphalt, appearing plastic deformations and asphalt formations to the sides of the pathology, indicating fluence in the material and it originated due to traffic loads and combined high temperatures. The second is the rutting with simple depression and without plastic deformations to the sides of the pathology. In this case, failure of the sublayers has occurred.

Left: Plastic deformation of the asphalt layer. Centre: Simple depression without rutting. Right: Pathology formation process

The common shallow causes of rutting are:

- Mechanical (S.MC):
- Traffic Loads,
- Base-subbase instability,
- Aggregate/Asphalt instability.

Traffic Loads

Evaluation of the Shallow Cause (Primary Inquiries)

Flexible pavements are designed using standards and codes to determine the total thickness, materials and number of layers to resist a number of load cycles in the lifespan of the road. The initial assumptions in the design can affect radically the level of maintenance the road needs to have. A low approach to the real vehicular loads affects the lifespan of the road, leading to an increase in the fatigue of the layers and stiffness of the flexible pavement, making the road more propense to cracks, rutting and potholes.

S.MC.06 How much has the element been subjected to traffic loads during the operation?	
0	Heavy traffic, trucks or similar is rare (1 or less in an hour)
25	Heavy traffic, trucks or similar is ocasional (5 or less in an hour)
50	Heavy traffic, trucks or similar is moderate (5-7 in an hour)
75	Heavy traffic, trucks or similar is frequent (8-9 in an hour)
100	Heavy traffic, trucks or similar is usual (10 or more in an hour)
NO DATA	There are no observations on the traffic in peak hours
NON APPLICABLE	The road is not subjected to traffic by its conception

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

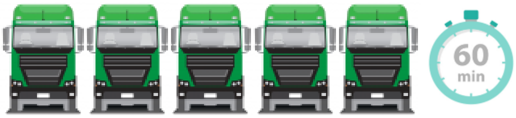
Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.xx]* Has Traffic Studies been produced prior to the Design Stage?
- *[D.DE.XX]* Is the traffic loading calculated according to AASHTO requirements, for design consistency?
- *[D.DE.32]* Is the asphalt designed to resist the traffic design load during its design life?
- *[D.OP.xx]* Is there any evidence that traffic load exceeding the design load has occurred?
- *[D.OP.02]* Is there any evidence that significant vehicle braking forces have been transferred to the asphalt pavement?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Traffic Loads Related Images	Score
1 truck per hour 	**0**
5/7 trucks per hour **or** **1 truck per 10 mins**  	**50**
More than 10 trucks per hour **or** **more than 2 trucks per 10 mins**  	**100**

Base-Subbase Instability

Evaluation of the Shallow Cause (Primary Inquiries)

Occurs when the subgrade exhibits wheel path depressions due to loading. In this case, the pavement settles into the subgrade ruts causing surface depressions in the wheel path. This is usually the result of one or both: inadequate subgrade preparation (e.g., compaction, replacement, etc.) and/or inadequate pavement structure (to reduce the loading on the subgrade to an acceptable level).

S.MC.xx Has the road deformed vertically but does NOT present lateral elevations (Type 2 Rutting)?	
0	Pavement does NOT present deformation to the sides and its depth is less than 1cm
25	-
50	Pavement does NOT present deformation to the sides and its depth is between 1cm -2cm
75	-
100	Pavement does NOT present deformation to the sides and it is deeper than 2cm
NO DATA	There are no observations on the deepness of the rutting
NON APPLICABLE	The road is not pavemented

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.DE.XX]* Is the material of the base-subbase compliant with the Pavement Design Catalogue of LGED?
- *[D.DE.XX]* Has the Geotechnical Team defined the optimal 95% Modified Proctor Compaction Index or CBR value for the base-subbase material?
- *[D.DE.XX]* Has the correct construction machinery been selected to compact the embankment material?
- *[D.EX.12]* Are the first layers of soil, composing the base and subbase of the road, compacted in all its surface?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Related Image	Image Score
	**0**
	**100**

Asphalt Instability

Evaluation of the Shallow Cause (Primary Inquiries)

The asphalt mixture properties are an important factor in the elastoplastic behavior of the asphalt mixture. A larger air void content, a higher reclaimed asphalt content, the use of unmodified and hard binders, and a low binder dosage have a negative impact on the mixture resistance against rutting.

Rutting is confined to the HMA mixture. Loads push down on the mixture and it flows away from the loading and up. Usually in mix rutting there is a distinctive raised elevation on the edges of the wheel path. There is no rutting in the subgrade.

S.MC.xx Has the road visible plastic deformations to the sides of the rut (Type 1 Rutting)?	
0	Pavement present plastic deformation to the sides and it is less deep than 1cm
25	-
50	Pavement present plastic deformation to the sides and its depth is between 1cm-2cm
75	-
100	Pavement present plastic deformation to the sides and it is deeper than 2cm
NO DATA	There are no observations on the deepness of the rutting
NON APPLICABLE	The road is not pavemented

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.DE.XX]* Is the extension and compaction of the asphalt clearly defined?
- *[D.EX.XX]* Have the Pavement Technical Specifications been followed during execution?
- *[D.EX.XX]* How consistent is the surface layer thickness throughout the paved surface (asphalt edge thickness versus centerline thickness)?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

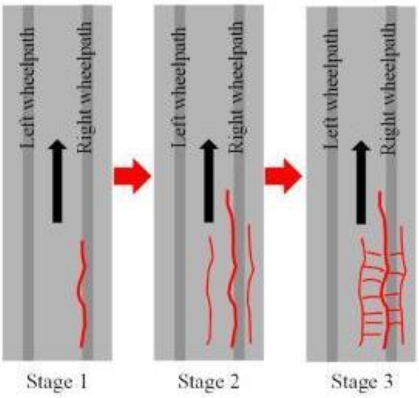
SCORING REFERENCE SYSTEM

Related Image	Image Score
	**0**
	**50**
	**100**

○ Surface cracking

Surface cracking phenomena definition

A series of interconnected cracks caused by fatigue failure of the bituminous surface under repeated traffic loading. As the number and magnitude of loads becomes too great, longitudinal cracks begin to form due to the stiffening process or excessive deformations that are occurring in the pavement, usually in the wheelpaths or in the vicinity. After repeated loading, these longitudinal cracks connect forming many-sided sharp-angled pieces that develop into a pattern resembling the back of an alligator or crocodile. In the figure below the process of formation of this surface cracking is illustrated.



Surface cracking control and maintenance poses a great importance in the prevention of further pathologies associated with the cracks, such as potholes, rutting, etc. Also, studies show that the cracking development is not ascribable to a single cause, but a combination of factors, which are going to be described in the following section.

An example of surface cracking can be seen below:

The common shallow causes of cracking are:

- Mechanical cause (ME)
  - Traffic Loads
- Environmental cause (EN)
  - Asphalt Aging

Traffic loads

Evaluation of the Shallow Cause (Primary Inquiries)

Flexible pavements are designed using standards and codes to determine the total thickness, materials and number of layers to resist a number of load cycles in the lifespan of the road. The initial assumptions in the design can affect radically the level of maintenance the road needs to have. A low approach to the real vehicular loads affects the lifespan of the road, leading to an increase in the fatigue of the layers and stiffness of the flexible pavement, making the road more propense to cracks, rutting and potholes.

S.MC.06 How much has the element been subjected to traffic loads during the operation?	
0	Heavy traffic, trucks or similar is rare (1 or less in an hour)
25	Heavy traffic, trucks or similar is ocasional (5 or less in an hour)
50	Heavy traffic, trucks or similar is moderate (5-7 in an hour)
75	Heavy traffic, trucks or similar is frequent (8-9 in an hour)
100	Heavy traffic, trucks or similar is usual (10 or more in an hour)
NO DATA	There are no observations on the traffic in peak hours
NON APPLICABLE	The road is not subjected to traffic by its conception

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.xx]* Has Traffic Studies been produced prior to the Design Stage?
- *[D.DE.XX]* Is the traffic loading calculated according to AASHTO requirements, for design consistency?
- *[D.DE.32]* Is the asphalt designed to resist the traffic design load during its design life?
- *[D.OP.xx]* Is there any evidence that traffic load exceeding the design load has occurred?
- *[D.OP.02]* Is there any evidence that significant vehicle braking forces have been transferred to the asphalt pavement?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Traffic Loads Related Images		Score
1 truck per hour		**0**
5/7 trucks per hour **or** **1 truck per 10 mins**		**50**
More than 10 trucks per hour **or** **more than 2 trucks per 10 mins**		**100**

Asphalt Aging

Evaluation of the Shallow Cause (Primary Inquiries)

The asphalt mixture properties, in particular those of the wearing course that first counteracts the cracking, are an important factor in the aging of the road. A larger air void content, a higher reclaimed asphalt content, the use of unmodified and hard binders, and a low binder dosage have a negative impact on the mixture resistance against surface cracking by impacting the aging of the road. Also, the premature deterioration of the pavement can also be caused by a deficient compaction of the sublayers.

This deterioration or aging of the road augments drastically the probability of apparition of surface cracking among other pathologies.

S.MC.xx Is the road visibly deteriorated or aged with signs of visible cracks or series of interconnected cracks?	
0	Pavement does not present any sign of disgregation or cracks
25	Pavement present mild surface disgregation or localized cracks
50	Pavement present surface disgregation and localized cracks
75	Pavement is moderately disaggregated, with multiple cracks and occasionally rutting marks
100	Pavement is heavily disaggregated, with generalized cracks and numerous rutting marks
NO DATA	There are no observations on the visible aging of the road
NON APPLICABLE	The road is not pavemented

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.01]* Are Design Standards properly identified at the Design Stage?
- *[D.DE.33]* Is the extension and compaction of the asphalt clearly defined?
- *[D.DE.XX]* Has the material of the base-subbase (gradation, void ratio, unit weight, moisture content etc.) been properly defined by the Geotechnical Team, consistent with the expected Design Load?
- *[D.DE.XX]* Has the correct construction machinery been selected to compact the embankment material ?
- *[D.OP.7]* Is the road pavement still within its expected design life, according to the Pavement Technical Specification document?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Related Image	Image Score
	**0**
	**50**
	**100**

Improper Base-Subbase Soil Properties

Evaluation of the Shallow Cause (Primary Inquiries)

Transverse cracks extend through the pavement at angles of approximately 90 degrees to the centreline of the pavement or to the direction of the roadway. These types of cracks are not usually associated with traffic loading.

S.MC.XX Has the road transverse cracking?	
0	There is no sign of transverse cracking in the road
25	There are slight signs of transverse cracking
50	Transverse cracking occurs frequently and discur along >5m in length
75	Transverse Cracks of <3mm width and >2.5m usually appear in the road
100	Transverse Cracks of >3mm width and >2.5m appear in the road consecutively
NO DATA	There are no observations on cracks in the road
NON APPLICABLE	The road is not pavemented

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.PL.xx]* Has a Geotechnical Investigation Campaign and Interpretative Report been produced prior to the Design Stage?
- *[D.DE.XX]* Has the road been constructed over an expansive clay soil?
- *[D.DE.XX]* Has the material of the base-subbase (gradation, void ratio, unit weight, moisture content etc.) been properly defined by the Geotechnical Team, consistent with the expected Design Load?
- *[D.DE.XX]* Has the Geotechnical Team defined the optimal 95% Modified Proctor Compaction Index or CBR value for the base-subbase material?
- *[D.DE.XX]* Has the correct construction machinery been selected to compact the base-subbase material ?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Related Image	Image Score
	**0**
	**50**
	**100**

Poor Joint Construction or Location

Evaluation of the Shallow Cause (Primary Inquiries)

A longitudinal joint is the interface between two adjacent and parallel asphalt mats. Improperly constructed longitudinal joints can cause premature deterioration of multilane asphalt pavements in the form of cracking and raveling. These distresses, caused by relatively low density (high air voids) and surface irregularity at the joints, can largely be avoided through proper construction techniques and equipment.

S.MC.XX Has the road thermal/construction joints?	
0	There are construction joints along the road and longitudinal joints, located in the separation of the lanes or where there is a rapid change in the road geometry or cross section
25	There are construction joints along the road and longitudinal joints, but some uncontrolled longitudinal cracking appears locally.
50	There are construction joints along the road and no longitudinal joints, but some uncontrolled longitudinal cracking of <5mm width appears locally.
75	There are construction joints sometimes along the road and no longitudinal joints; generalized longitudinal cracking is visible.
100	There are no joints along the road, visibly forming large longitudinal cracks >15mm width in between the lanes.
NO DATA	-
NON APPLICABLE	Joints are not needed by its conception

Note: Please refer to 'Scoring Reference System' section to assist in the evaluation of the above rating

Evaluation of Potential Deep Causes (Secondary Inquiries)

In order to further investigate the potential hidden cause responsible for the origin of the observed pathology, the following axes of deep investigation shall be undertaken, but not limited to:

- *[D.DE.XX]* Are longitudinal joints locations specified in the Design Drawings?
- *[D.EX.XX]* Have construction joints been prepared to separate the different asphalt construction days?

0	25	50	75	100	NO DATA	NON APPLICABLE
All of the time	Often	Some of the time	Rarely	None of the time	No collected data	Non observable

SCORING REFERENCE SYSTEM

Related Image	Image Score
	**0**
	**100**

PART-2: TOOLKIT USER MANUAL

A spreadsheet-based Toolkit for conducting Failure Analysis has been developed. The intention is for LGED to either upload it on the website or store it in the Google Shared Drive, allowing LGED engineers to download it from any location and utilize it. This user manual provides instructions on how to effectively use the Toolkit. Currently in its Beta Version, the Toolkit comprises nineteen sheets and will undergo further refinement based on a series of field tests.

1. Introduction

In the following sections and subsections, the functioning of the toolkit (beta version) is going to be extensively explained, in order to accurately guide new users into the depths of the toolkit.

The toolkit results have two (2) different methods to be validated:

1. The junior engineer can explore the pathologies identified in the inspection visit and then reviewed by the senior engineer in order to address finally the pathology scoring;

2. An independent assessment of the local engineers, LGED engineers, specialized in different areas of knowledge, have a consensus meeting which serves as a cross-check of the scoring of the questions. In this meeting, a final scoring of the toolkit would be done.

With this in mind, the toolkit has been developed to be user-friendly, downloadable, accessible at all times (not dependent on Wi-Fi network) and ready to be used by qualified personnel (civil engineer/technician), both with and without previous experience in pathologies.

The toolkit is the product of the state-of-the-art for both approaches, bottom-up and top-down, to forensic engineering, as explained in another document 'Failure Analysis Framework: Roads and Bridges'.

In the nut shell and as a quick summary (refer to Failure Analysis Framework for further detail), in the bottom-up approach, the pathology has been generated and it is visible in the infrastructure, and the engineer needs to explore the upstream cause of it. The toolkit helps to explore different hypotheses, discard them, score and finally reach the deepest cause of the pathology, which will be explained in further subsections.

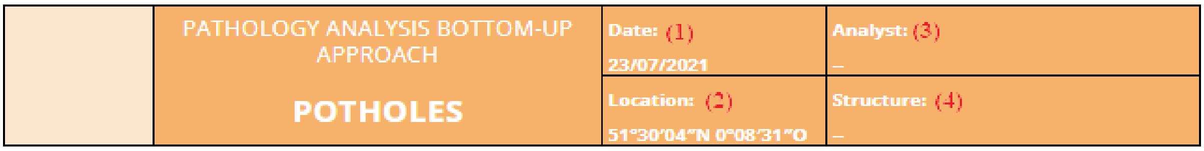
On the other hand, the top-down approach is a generalist approach to the origin of the pathology, departing from the technical documentation available and trying to identify design weaknesses and not appropriate decision strategies that could potentially originate the observed pathology and the corresponding triggering effect.

2. Interface

The toolkit has been designed with the end-user in mind, ensuring maximum accessibility. It is developed as a Microsoft Excel file specifically tailored to be hosted on the LGED webpage. This means that anyone who needs to use the toolkit can simply be provided with a link to access it.

The first page that users see is the main 'Analysis' sheet. This sheet serves as the primary workspace where users will spend 99% of their time working.

In 'Analysis' different sections can be differentiated:



PATHOLOGY ANALYSIS BOTTOM-UP APPROACH

POTHOLES

Date: (1)
23/07/2021

Analyst: (3)
–

Location: (2)
51°30′04″N 0°08′31″O

Structure: (4)
–

2.1 Header

In the header section, the Date of the Analysis (1), Location (2), Analyst (3) and Structure (4) have to be filled. Note that the name of the pathology is going to be selected lately.

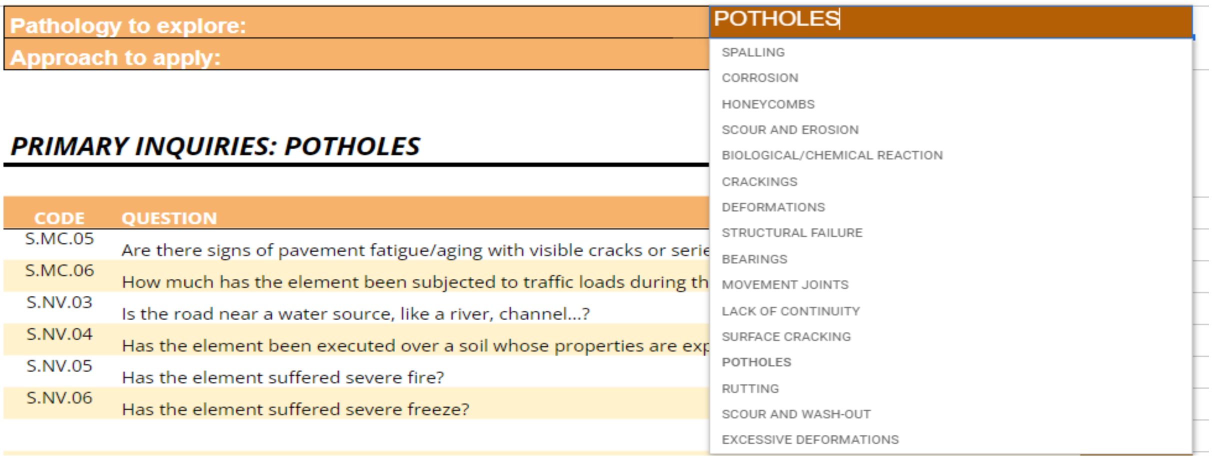
2.2 Pathology and Method Selection

Pathology to explore: POTHOLES

Approach to apply: BOTTOM-UP

In this section, the pathology to be explored is selected. Note that if there is more than one pathology to explore, there will be one copy of the toolkit for each of them. Equally, if the user is in the necessity to explore more than one, the same rule applies, the document will be copied and assigned to one pathology at a time.

This is a drop-down tab, in which the user has to click on it, and the possible selections will appear:



Pathology to explore: POTHOLES

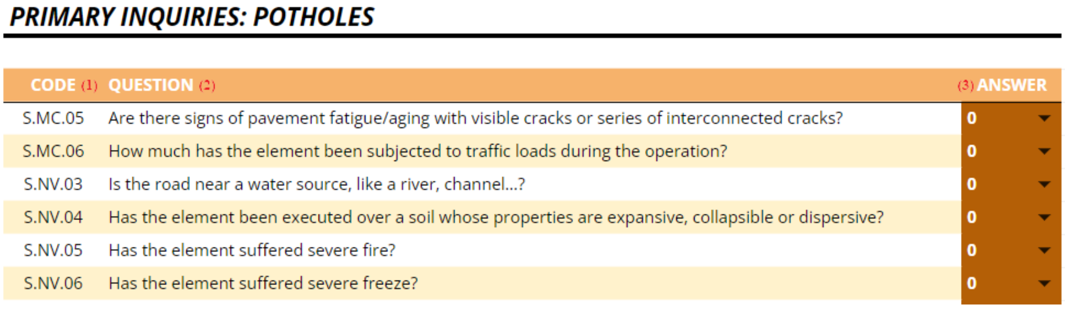
Approach to apply:

PRIMARY INQUIRIES: POTHOLES

CODE	QUESTION
S.MC.05	Are there signs of pavement fatigue/aging with visible cracks or serie
S.MC.06	How much has the element been subjected to traffic loads during th
S.NV.03	Is the road near a water source, like a river, channel...?
S.NV.04	Has the element been executed over a soil whose properties are exp
S.NV.05	Has the element suffered severe fire?
S.NV.06	Has the element suffered severe freeze?

Note that all the pathologies listed in the drop-down menu coincide with the number of pathologies in which there are ‘Guidance Materials’. The user should select the pathology to be explored and automatically the header will change accordingly, and so the questions in ‘Primary Inquiries’.

2.3 Primary Inquiries Section



PRIMARY INQUIRIES: POTHOLES

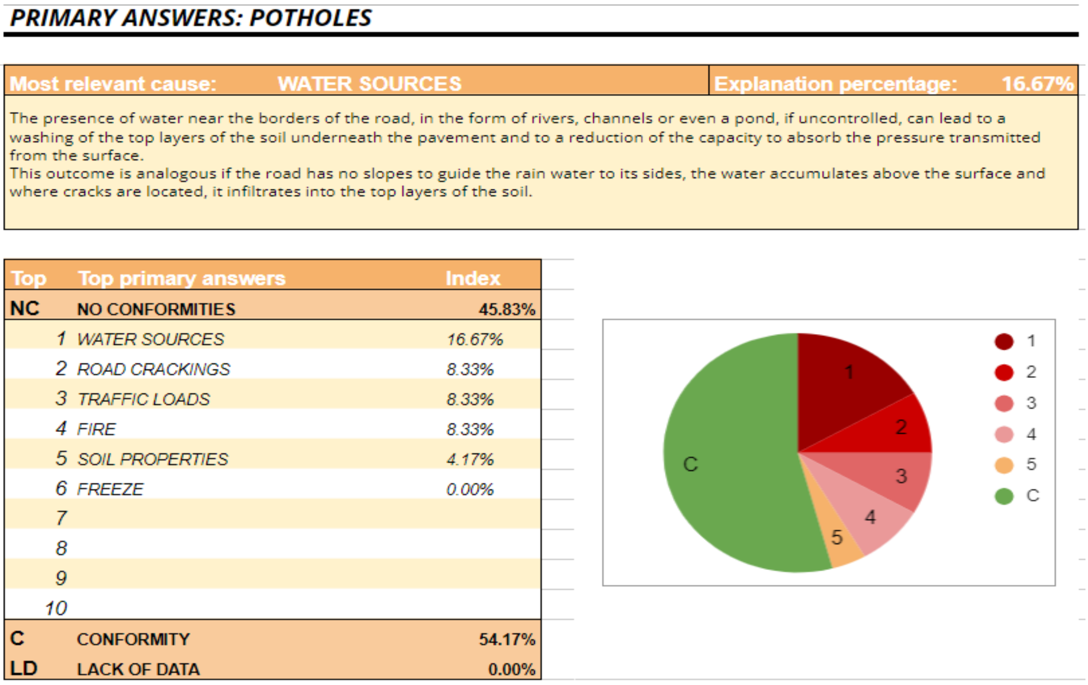
CODE (1)	QUESTION (2)	(3) ANSWER
S.MC.05	Are there signs of pavement fatigue/aging with visible cracks or series of interconnected cracks?	0
S.MC.06	How much has the element been subjected to traffic loads during the operation?	0
S.NV.03	Is the road near a water source, like a river, channel...?	0
S.NV.04	Has the element been executed over a soil whose properties are expansive, collapsible or dispersive?	0
S.NV.05	Has the element suffered severe fire?	0
S.NV.06	Has the element suffered severe freeze?	0

1. The coding of the question.
2. The question regarding the Shallow Cause of the pathology itself
3. The answer of the User to the question. The scoring and how the user has to interact with this will be explained in the ‘Scoring the Toolkit Questions’ section.

In this section the first questions of the toolkit appear when selecting a pathology to explore. The name of the pathology will change and the questions* as well.

***Note of the developers:** It is extremely important to reload the Toolkit when changing a pathology in the drop-down tab.

2.4 Primary Answers Section



PRIMARY ANSWERS: POTHOLES

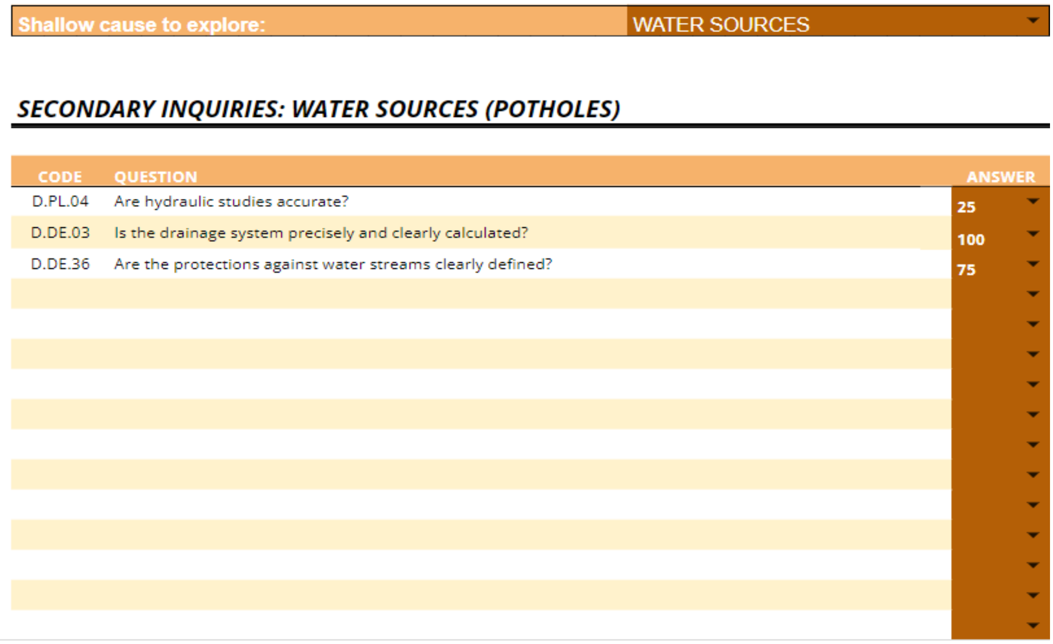
Most relevant cause: WATER SOURCES | Explanation percentage: 16.67%

The presence of water near the borders of the road, in the form of rivers, channels or even a pond, if uncontrolled, can lead to a washing of the top layers of the soil underneath the pavement and to a reduction of the capacity to absorb the pressure transmitted from the surface.
This outcome is analogous if the road has no slopes to guide the rain water to its sides, the water accumulates above the surface and where cracks are located, it infiltrates into the top layers of the soil.

Top	Top primary answers	Index
NC	NO CONFORMITIES	45.83%
1	WATER SOURCES	16.67%
2	ROAD CRACKINGS	8.33%
3	TRAFFIC LOADS	8.33%
4	FIRE	8.33%
5	SOIL PROPERTIES	4.17%
6	FREEZE	0.00%
7		
8		
9		
10		
C	CONFORMITY	54.17%
LD	LACK OF DATA	0.00%

The primary or shallow cause of the pathology is briefly explained and a 'Tier List' appears at the bottom with a pie-chart at the right of the Toolkit. This allows the user to visibly see how much of the explored pathology is due to the different hypothesis or shallow causes presented.

2.5 Secondary Inquiries Section



Shallow cause to explore: WATER SOURCES

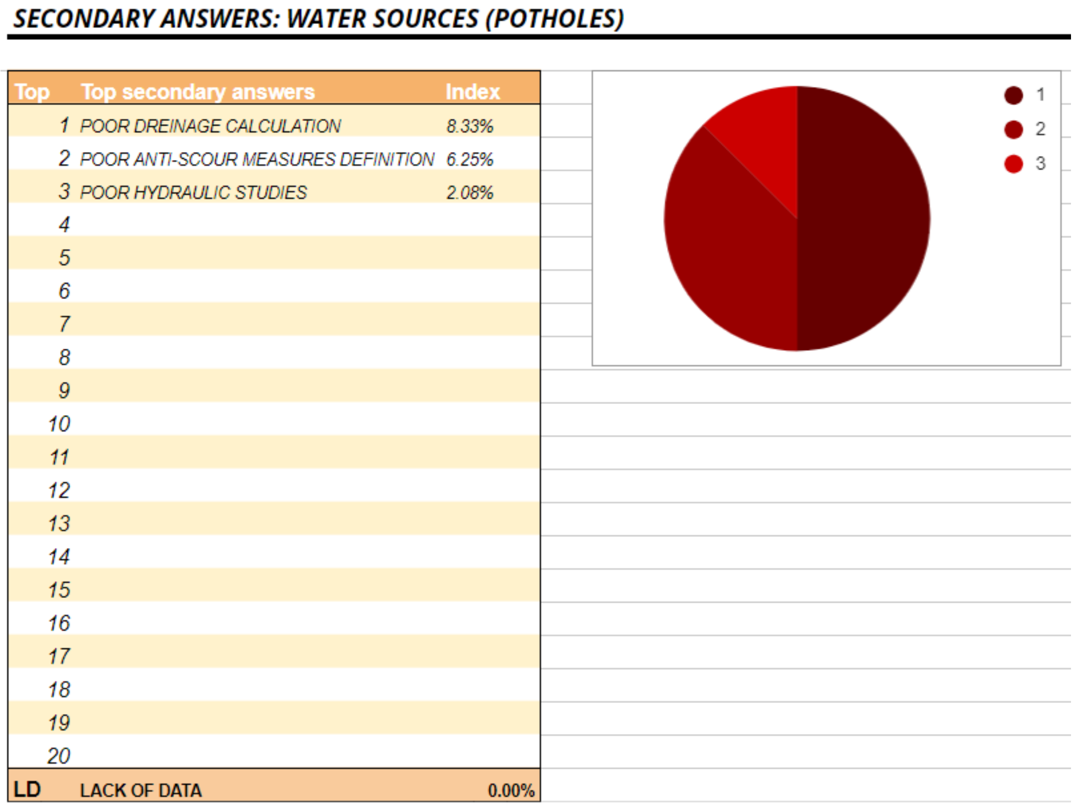
SECONDARY INQUIRIES: WATER SOURCES (POTHOLES)

CODE	QUESTION	ANSWER
D.PL.04	Are hydraulic studies accurate?	25
D.DE.03	Is the drainage system precisely and clearly calculated?	100
D.DE.36	Are the protections against water streams clearly defined?	75

Once the user has seen where the pathology mostly originates, the deepest or secondary inquiries can be explored.

Another drop-down tab is available to select the shallow cause to explore. Normally, the user will want to explore the most relevant (higher-scoring) pathology, however, the developers encourage the user to explore at least the top two (2) primary answers on the look for the same deepest cause or multifactor cause.

2.6 Secondary Answers Section



SECONDARY ANSWERS: WATER SOURCES (POTHOLES)

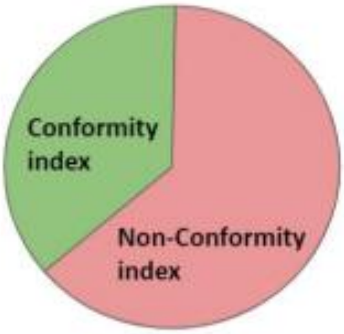
Top	Top secondary answers	Index
1	POOR DREINAGE CALCULATION	8.33%
2	POOR ANTI-SCOUR MEASURES DEFINITION	6.25%
3	POOR HYDRAULIC STUDIES	2.08%
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20		
LD	LACK OF DATA	0.00%

Analogue to the Primary Answers Section, the Top Secondary Answers are presented in a Tier List, with the Index of participation in the pathology. It is intended to clear the bottom, root, or deepest cause of the pathology, serving as the explanation of why the Primary Explanation or Visible Cause of the pathology originated in the first place.

3. Scoring the Toolkit's Questions

The exploration of hypotheses normally is not an objective task and in order to help the User and the Authority to have a Standardized Criteria, a scoring system is implemented.

The developers thought even giving a scoring range to respond to a question, would fall into subjectivity, thus, the idea of the 'Guidance Materials' is implemented. The balance is found by giving the Shallow Causes a range-based scoring regarding the visible cause of the pathology and its level of aggravation and the Deep Causes, which are harder to range, will introduce the subjectivity of the User of the Toolkit.



It is necessary to define a mathematical index that allows an easy overview of the participation of the different shallow causes on the pathology appearance. This index should move from 0% to 100%, where 100% would indicate the worst situation possible and 0% would indicate the best situation possible, there isn't any trace of problems. This index will be named Non-Conformity Index. To make it easier to visualize, a Conformity Index will be used too. The addition of Conformity and Non-Conformity indexes always add up to 100%.

How-to properly score a Shallow Cause Question in the Toolkit

1) Identify the pathology from the pictorial evidence.
2) Open the Guidance Material of the Pathology
3) Open the Toolkit and select the pathology in the 'Pathology and Method Selection'. Reload is recommended after selecting the pathology in the drop-down tab
4) The questions of the Shallow Causes in the Toolkit are correlated with the Shallow Questions explained in the Guidance Materials.
5) Go through each Shallow Cause section in the Guidance Material, with the help of the Related Images to assess the severity of the question in comparison of the pathology in study and score the questions based on the ranges in the table and introduce that score in the toolkit in the corresponding question.
6) Once all Shallow Questions are responded, the top shallow cause which has a higher non-conformity index should appear as the selected most probable cause of the pathology, along with the tier list of the rest of shallow causes and its percentage of

contribution.

7) In order to explore the Deep Causes of the Shallow Cause, the shallow cause must be selected and the questions should pop-up underneath it in the Secondary Inquiries Section. If this does not happen, please reload the toolkit again.

8) The scoring system of the deep causes is analogue to the shallow causes, in the Guidance Materials the scoring system can be found as well. 100% is always the worst-case scenario.

Note from the developers: We encourage the User to explore the top two (2) most probable causes to look after correlations in the flaws of both shallow causes within the deep causes (i.e. improper or poor preliminary studies).

ANNEX A. Example

An example is going to be presented. The pathology to be studied is going to be the corrosion of rebars.

The corrosion of metals is a chemical process produced by a redox reaction where the metal gives electrons (anode) to another substance (cathode) that receives them. This explanation, however, is of small use to analyze the corrosion of rebars.

In the case of corrosion of rebars, the concrete protects the reinforcing bars due to its alkaline nature. The alkalinity of concrete provides a passivating film that prevents oxidation. However, concrete is a porous material, and it cannot prevent indefinitely the presence of aggressive substances that eventually will produce corrosion. Thus, there are two main reasons for corrosion of rebars.

- The presence of de-passivating ions (normally, chlorides) on the surface of the rebars.
- The loss of alkalinity in the concrete.

As a plus, the presence of water or humidity in contact with the metal will act as a catalyst of the corrosion, so it will be another factor to count on.

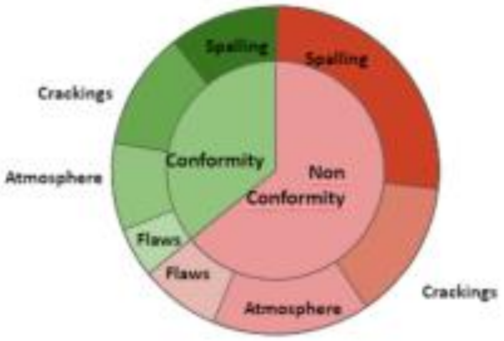
According to this, some shallow causes can be brainstormed for the corrosion of rebars:

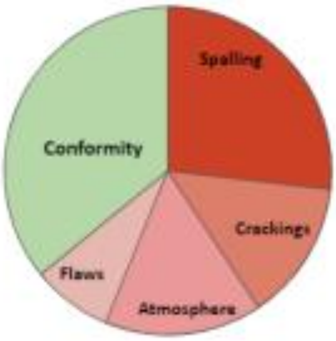
- **Crackings (Concomitant Pathology):** Crackings are deep enough as to reach the rebars under the concrete cover that is not properly protected anymore;
- **Spalling (Concomitant Pathology)**: Spalling is deep enough as to reach the rebars under the concrete cover, that is not properly protected anymore;
- **Aggressive atmosphere (Environmental):** Aggressive atmospheres are humid, maritime and chemically aggressive ones. Humidity penetrates through the concrete and catalyzes the corrosion when in contact with rebars. Maritime atmospheres, besides humid, are rich in chlorides. As for chemically aggressive atmospheres, they have gasses that attack the metal, the concrete, or both;
- **Flaws in the concrete (Environmental):** Flaws in the concrete can be presented in many ways: concrete has a higher porosity than desired because the aggregates do not have proper size or shape, there was not a right vibration of the mix, the admixtures are not the right ones to protect the concrete or the metal against the atmosphere, etc. In all of them, concrete is not providing the physical or the chemical protection against corrosion the metal needs.

Some other primary explanations might be explored; however, these ones will suffice to go on with the example.

Each shallow cause contributes both to Conformity and the Non-Conformity indexes. For example, let's say, arbitrarily, that spalling contributes 40% to the indexes. When spalling is totally developed (what totally developed means will be determined in the pertinent Guidance Material), it will score its 40% in the Non-Conformity Index. When inexistent, the 40% corresponding to spalling will increase the Conformity Index. Intermediate situations will distribute the 40% between both.

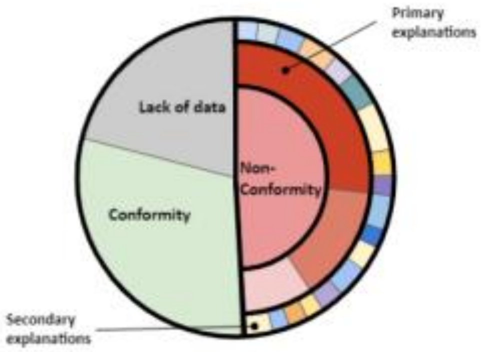
However, as the main objective of this analysis is to determine the causes of the pathology, it is just Non-Conformity that needs to be decomposed. Decomposing the Conformity Index does not add any information to the study, furthermore when it is already known despite being hidden: when knowing spalling is scoring 27% in Non-Conformity Index, the remaining 13% is necessarily part of the Conformity Index.





There is another factor that has not been presented yet, and it is the lack of data. Lack of data is produced when some shallow cause cannot be explored (for example, the operator cannot answer some questions related to the shallow causes. In this case, the percentage corresponding to that shallow cause would add up to a lack of data score.

Finally, when a shallow cause is not needed to be explored because it does not apply to the specific structure under study, the shallow cause will be removed from the indexes so as not to distort them adding up as Conformity or Lack of Data.



It is important to note that it is not possible to determine, in the first place, if there is a value of the Conformity Index that will guarantee the safety and comfort of the structure. Intuition leads to think so, however, it might be that some shallow causes remain totally conform while another is the one that produces the pathology. A high Conformity Index does not imply but shallow causes are far from totally developed (which eventually will narrow the final reasons leading to the pathology, the deep causes).

Finally, each shallow cause is likewise decomposed in several deep causes that will determine in which step or steps of the lifecycle there was a lack of compliance that lead to the happening of the shallow causes and the pathology (Picture 5).

These deep causes are the ones where pathology relies on. Understanding its weight in the pathology appearance will be the goal of the toolkit.

ANNEX B. Advanced Developer Capabilities

The toolkit has more tabs than the User-Friendly 'Analysis' Tab. In this section the instructions for the new developers of the Toolkit are presented.

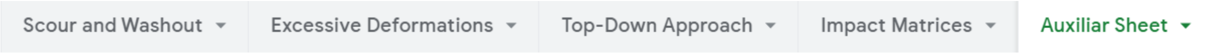
In the normal case of adding a new pathology, or the calibration of the questions and scoring of the pathologies already existing, the instructions are the following:

The developers of the sheet keep the door open to the calibration of the sheet, whether the questions are less accurate to the region where the pathology itself, or to penalize a common mistake that is being observed among the pathologies of the same type.

In order to do the calibration of the punctuation, **the 'scoring system' section of the Failure Analysis Report must be reviewed** before. Once the new developer understands the weighted scoring system, the easiest way to penalize a common error is to add more questions regarding the matter.

How to add questions to the Toolkit (without breaking the sheet)

1) Localize the 'Auxiliar Sheet' at the end of the tabs in the bottom of the toolkit



2) The first thing the developer should differentiate is if the Question relates to a Shallow or a Deep Cause. A Shallow Cause is a visible cause that can explain the occurrence of the pathology, whether the Deep Causes are the root cause of the problems and they are usually found in the documentation of the project in the planning, design, construction, operation and maintenance phase or the absence of specification in any of the phases.

    a) The question is related to a new Shallow Cause:

    i. The Guidance Material of the Pathology with the new Shallow Cause has to be updated accordingly, with a new section describing the Shallow Cause with a Scoring Section and an Image Related Section, to help the User to score the new question;

    ii. A series of Deep Causes Questions have to be written regarding the Shallow Cause to explain the apparition of the Visible Cause of the problem. A rule has to be specified in order to maintain the scoring system stable. The same number of questions have to be specified in the different phases of the infrastructures, if possible, to maintain the scoring of the phases stable between them (25% each);

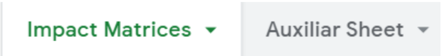
    iii. In the Toolkit, localize the Shallow Causes List. The coding of the question is S (Shallow Cause) + MC (Mechanical)/NV (Environmental)/ETC. + NUMBER;

    iv. When finding the category of the Shallow Cause, RMB (right mouse button in the Row Number in the left and click on 'Add Row'. This is the only way to add information to the Auxiliar Sheet tab. Write down the CODE of the question immediately above the New Created Question;

    v. Fill the necessary columns with the information requested. The question has been created;

    vi. To associate the new question to the pathology, the developer has to go to the 'Impact Matrices' Tab;

    vii. The Outer Impact Matrix has to be updated with the information created in the Auxiliar Sheet. Localize the coding of the question of the one newly created, in that same row, right click on the left side of the



sheet where the number of the rows appear and 'Add one row below';

viii. Then, select the question above, and drag down the formula by clicking on the bottom right corner and dragging down the blue little square;

S.NV.04 SOIL PROPERTIES

ix. The new question has been updated in the matrix. Now an 'X' has to be put in to assign the question to the corresponding pathologies which are specified in the columns of the matrix;

x. Once assigned, scroll down to the 'Inner Impact Matrix', it's time to assign the shallow cause to the deep causes. Notice that the assigned new Shallow Cause must appear in the columns of the pathology it refers to;

xi. To create the Deep Causes questions, follow the same steps from 'iv to ix' in the 'Deep Causes List' and in 'Inner Impact Matrix';

xii. Analogue to ix) an X has to be assigned to match the deep causes questions to the corresponding shallow cause;

xiii. Now the Analysis Tab should be receiving all the new information created;

<u>Note</u>: Double Check if the X has been put in the right place by trying the Analysis tab.

b) The question is related to a new Deep Cause:

I. Follow steps from 'iv to ix' in the 'Deep Causes List' and in 'Inner Impact Matrix' in the previous explanation;

ANNEX C. Overall view of Primary and Secondary Inquiries

The purpose of this Annex is to, but not limited to:

a) Overall view of the Primary and Secondary Inquiries, without having to dive in each of the pathologies;
b) To guarantee completeness of the inquiries with each section, and;
c) To guarantee that all project stages of the infrastructure design life is duly covered;

Additionally, please note that some documents listed here have a link associated with it. **Please make sure that all Guidance Material is properly stored in the same and unique folder.**

Here below is the standard pathology structure inquiry, for both shallow and deep causes:

PATHOLOGY NAME

Shallow Cause n.1 Investigation

S.XX.XX (Codification) Shallow cause - primary inquiry -

- [D.XX.XX] (Codification) **Deep cause question n.1** - secondary inquiry -
- [D.XX.XX] (Codification) **Deep cause question n.2** - secondary inquiry -
- ...

Shallow Cause n.2 Investigation

S.XX.XX (Codification) Shallow cause - primary inquiry -

- [D.XX.XX] (Codification) **Deep causes question n.1** - secondary inquiry -
- [D.XX.XX] (Codification) **Deep causes question n.2** - secondary inquiry -
- ...

Please observe that this structure allows you to add / incorporate as many questions the developer would like, as long as these new inquiries are properly introduced in the Toolkit with the corresponding cross-relationship and without jeopardizing the balance between stages of the development of a project.

BRIDGE PATHOLOGIES

BEARING MALFUNCTIONING

Bearing excessive deformation/displacement/rotation

S.MC.XX Is the bearing excessively deformed, displaced or rotated (please refer to Guidance Material for scoring assessment range)?

- *[D.DE.XX]* Has the bearings' expected design deformation been defined in the Set of Calculations?
- *[D.DE.XX]* Does the bearing Technical Specifications match the type of support in the theoretical model in the design?
- *[D.DE.XX]* Are the bearing anchors (type, diameter, position, and anchor length) specified in the Design Drawings?
- *[D.DE.XX]* Are the bearings locations clearly indicated in the Design Drawings?
- *[D.EX.XX]* Have the bearings been installed according to the specifications (location, height, and Temperature setting) as per the Design?

Bearing Aging

S.MC.XX Has the bearing reached the limit of its lifespan (please refer to Guidance Material for scoring assessment range)?

- *[D.MN.xx]* Has the last inspection of the mechanical device been done less than two years ago?
- *[D.MN.xx]* Has the last maintenance of the mechanical device been done less than five years ago?
- *[D.MN.xx]* Is the mechanical device less than the specified Device Design Life (typically 15-20 years design life)?
- *[D.MN.xx]* Are the elastomeric pads cracked?
- *[D.MN.xx]* Are the mechanical devices NOT exposed to marine ambient?
- *[D.DE.XX]* Are drainage systems or minimum surface slope implemented to prevent water accumulation over the mechanical device?

CORROSION

Presence of water/moisture

S.NV.XX Is the element of study visibly affected by water presence (please refer to Guidance Material for scoring assessment range)?

- *[D.DE.XX]* Has the crack width been evaluated in the Set of Calculations?
- *[D.DE.XX]* Is the aggressivity of the environment properly defined and assessed in the Set of Calculation or Design Brief?
- *[D.DE.XX]* Is the concrete cover defined based on the expected environmental aggressivity such as salinity, moisture, chlorides etc.?
- *[D.DE.XX]* Is the concrete water/cement ratio well defined for the expected environment?
- *[D.DE.XX]* Are drainage systems or minimum surface slope implemented to prevent water accumulation over the structure?
- *[D.EX.XX]* Has the design concrete water/cement ratio maintained during the execution according to the Concrete Technical Specifications?
- *[D.MA.XX]* Has water infiltration been observed during the lifespan of the bridge?

Exposure to Chlorides

S.MC.xx Is the structure within 50 km of the shoreline??

- *[D.DE.XX]* Is the concrete exposure category properly defined?
- *[D.DE.XX]* Is the concrete cover designed for the expected chloride intrusion?
- *[D.DE.XX]* Is the concrete water/cement ratio well defined for the expected exposure?

Fire Exposure

S.NV.05 Has the element suffered severe fire exposure resulting in temperature grading, leading to concrete spalling and ultimately to rebar corrosion?

CRACKING

Structural overload

S.MC.XX What width do the cracks have (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.XX]* Do the structure's design and construction requirements consistent with the approved LGED Design Standards (please refer to Guidance Material for LGED Design Standards list)?
- *[D.DE.XX]* Does the structure have a structural calculation (internal efforts) for all its components (structural capacity higher than load demand) ?
- *[D.DE.XX]* Does the design have a crack control calculation or justification?
- *[D.DE.XX]* Does the developed numerical model for the analysis of the infrastructure captures the expected behaviour?
- *[D.DE.XX]* Are the Structural Drawings clear/legible and do not provide any contradictory information?
- *[D.MA.XX]* Have the construction materials been procured, stored, and handled as per the Material Technical Specification document?
- *[D.MA.XX]* Are certificates for each of the construction materials consistent with the Material Technical Specification document?
- *[D.EX.XX]* Has the concrete been placed appropriately; such as ensuring slump value, appropriate formwork rigidity and cleanness, compliance to vibrations limits, and curing process ?
- Has the curing process, prior to any preliminary loading, last for 27 days (+/- 2 days)?
- *[D.OP.XX]* Has the structure NOT suffered from loads exceeding the Design Load during its construction and operational period?

Temperature and shrinkage cracking

S.NV.XX Has the structure experienced thermal/shrinkage cracking (please refer to Guidance Material for scoring assessment range)?

- *[D.DE.XX]* Does the structure allow thermal expansion, using thermal joints or sliding bearings?
- *[D.DE.XX]* Does the design have a thermal/shrinkage calculation?
- *[D.DE.XX]* Are the Structural Drawings clear/legible and do not provide any contradictory information?
- *[D.MA.XX]* Has the concrete been placed appropriately; such as ensuring slump value, appropriate formwork rigidity and cleanness, and compliance to vibrations limits?
- *[D.EX.XX]* Has the concrete curing process been followed according to the Material Technical Specification document ?

DEFORMATIONS

Deck Slab capacity

S.MC.XX Is the deck slab visibly deformed (larger than L/300) (please refer to Guidance Material for scoring assessment range)?

- *[D.DE.XX]* Does the slab have adequate reinforcement to carry the resultant bending moment demand in both directions, independently?
- *[D.DE.XX]* Does the slab have adequate reinforcement to carry the resultant shear demand in both directions, independently?
- *[D.DE.XX]* Does the reinforcement in either direction qualify the 'Temperature and Shrinkage Criteria'? i.e $A_s > A_{temp}$
- *[D.DE.XX]* Does the slab have enough reinforcement to resist the local punching shear of the vehicle wheels?
- *[D.DE.XX]* Does the deck slab comply with minimum reinforcement criteria, in both directions?
- *[D.EX.XX]* Does the rebar/reinforcement size and spacing are consistent with the Design Drawings?
- *[D.EX.XX]* Does the slab thickness match the indications in the design?

Disproportion of the deck slab geometry

S.MC.XX Is the deck slab geometry proportioned (please refer to Guidance Material for scoring assessment range)?

- *[D.DE.XX]* Does the slab thickness meet the "rule of thumb" of Thickness>Length/16 for simply-supported slabs and Thickness>Length/25 to truss-based bridge?
- *[D.DE.XX]* Has the deck slab enough transverse beams (diaphragms) to ensure A/B proportion less than 1.5?
- *[D.DE.XX]* Does the slab have adequate reinforcement to carry the resultant moment and shear demand in both directions, independently?
- *[D.DE.XX]* Is the deck slab less deformed than L/300 (L is the larger of A and B)?

HONEYCOMBS

Reinforcement General Arrangement

S.MC.XX Are the rebars properly spaced (please refer to Guidance Material for scoring assessment range)?

- *[D.DE.XX]* Is the minimum rebar spacing properly defined in the Design Drawings?
- *[D.DE.XX]* Is the minimum mechanical and geometrical cover defined in the design and in the Design Drawings?
- *[D.EX.XX]* Is the minimum rebar spacing properly executed (i.e: rebar and cover spacers) on site as per the Design Drawings?
- *[D.EX.XX]* Is the minimum mechanical and geometrical cover executed on site as per the Design Drawings?

Concrete Definition

S.MC.xx Are the concrete mechanical properties consistent with the Concrete Technical Specification (please refer to Guidance Material for scoring assessment range)?

- *[D.DE.XX]* Is the aggregate grading (size of the aggregate) properly defined in the Concrete Technical Specification (Design Stage)?
- *[D.DE.XX]* Is the amount of the aggregate unit weight, void ratio, absorption and surface moisture properly defined in the Concrete Technical Specification (Design Stage)?
- *[D.DE.XX]* Is the water cement ratio properly defined in the Concrete Technical Specification (Design Stage)?

Concrete Pouring Process

S.MC.XX Has the concrete element been properly executed (please refer to Guidance Material for scoring assessment range)?

- *[D.EX.XX]* Does the aggregate grading used in construction is consistent with the requirements set in the Concrete Technical Specification (Design Stage)?
- *[D.EX.XX]* Is the amount of the aggregate per cubic meter properly executed (Construction Certificates/Reports)?
- *[D.EX.XX]* Is the amount of water per cubic meter of cement properly executed (Construction Certificates/Reports)?
- *[D.EX.XX]* Has the slump test been performed for each concrete batch?
- *[D.EX.XX]* Has the concrete been placed within the suggested time frame without "hampering" workability?
- *[D.EX.XX]* Has the concrete been always poured from less than 1m high?
- *[D.EX.XX]* Has the concrete element been vibrated according to LGED Standard document or Material Technical Specification document?

MOVEMENT JOINT MALFUNCTIONING

Joint Deterioration

S.MC.XX Has the joint deformed excessively under design load or has been severely deteriorated (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.01]* Are Design Standards properly identified at the Design Stage?
- *[D.DE.XX]* Has the thermal expansion/contraction calculation compliant with the Design Standards?
- *[D.EX.XX]* Has the mechanical device been designed following seismic reinforcement guidelines, when applicable?
- *[D.MN.xx]* Is the mechanical device age less than the specified Device Design Life (typically 15-20 years design life)?
- *[D.EX.XX]* Does the constructed joint match the specifications from the design?

Clogged joint

S.NV.XX Has clog material/debris been accumulated within the joint expansion zone area (please refer to Guidance Material for scoring assessment range)?

- *[D.MN.xx]* Has the joint Seal been damaged?
- *[D.MN.xx]* Has the last inspection of the mechanical device been done less than 2 years ago?
- *[D.MN.xx]* Has the last maintenance of the mechanical device been done less than 5 years ago?
- *[D.MN.xx]* Is the mechanical device age less than the specified Device Design Life (typically 15-20 years design life)?
- *[D.MN.xx]* Has the element not been exposed or is not exposed to marine ambient

LACK OF CONTINUITY

Poor connection design between key structural elements

S.MC.XX Is there reinforcement connecting the two concrete elements in the design (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.01]* Are Design Standards properly identified at the Design Stage?
- *[D.DE.XX]* Do the connection reinforcement have enough anchorage capacity to develop the reinforcement full strength?
- *[D.DE.XX]* Is the reinforcement detailing (length, diameter, position, mechanical and geometrical cover) clearly defined in the Structural Drawings and do not provide any contradictory information?
- *[D.EX.XX]* Has the structure been executed following the Design Drawings?

Poor execution (Planning and/or Procurement Stages)

S.MC.XX Has the concreting of the elements been stopped during execution (please refer to Guidance Material for scoring assessment range)?

- *[D.EX.XX]* Has the concreting strategy been planned before the construction?
- *[D.EX.XX]* If uncontrolled stops happen during concreting, have mitigation measures been taken to prevent the concrete discontinuity?
- *[D.EX.XX]* Is the poor execution resulting from the lack of coordination between several contractors/construction works onsite?

SCOUR AND EROSION

Water Erosion

S.NV.XX Has the water eroded the soil material underneath the foundations/abutment/piers (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.xx]* Was there any hydraulic study done before the Design Stage and taken into account into the design?
- *[D.DE.xx]* Are the pier/piles protections defined in the design?
- *[D.EX.xx]* Are the pier/piles protections executed as per the design?
- *[D.DE.xx]* Is the abutment protection defined in the design?
- *[D.EX.xx]* Is the abutment protection executed as per the design?
- *[D.MN.xx]* Has the last inspection of the pier/piles/abutment been taken in less than two (2) years?

SPALLING

Corrosion

S.PT.02 Has corrosion of rebars been observed (please refer to Guidance Material for scoring assessment range)?

- *[D.DE.XX]* Are there calculations/estimations of the width of the expected cracks in the reinforced concrete?
- *[D.DE.XX]* Is the aggressivity of the environment such as moisture, salinity, chloride and others, properly addressed and defined at Design Stage?
- *[D.DE.XX]* Is the concrete mechanical cover designed for the expected environmental aggressivity?
- *[D.DE.XX]* Is the concrete water/cement ratio well defined for the expected environment?
- *[D.DE.XX]* Are there drainage systems to prevent water accumulation over the structure?
- *[D.EX.XX]* Has the concrete water/cement ratio been controlled during the execution according to the Material Specification document?
- *[D.MA.XX]* Has moisture infiltration/penetration in the concrete elements been observed during the lifespan of the bridge?

Over compression

S.MC.01 Is there signs of the pathology being produced in an over-compressed region (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.01]* Are Design Standards properly identified for compression elements at the Design Stage?

- *[D.DE.XX]* Are compressed elements compliant with the Design Standards?
- *[D.MA.XX]* Have the construction materials been procured, stored, and handled as per the Material Technical Specification document?
- *[D.EX.XX]* Has the structure been executed following the Design Drawings?

Impacts

S.MC.02 Has the element suffered any loading exceeding the Design Load (Accidental/Extreme load) high impacts during the design life of the structure (please refer to Guidance Material for scoring assessment range)?

STRUCTURAL FAILURE

Structural Collapse

S.NV.XX Has the structure collapsed (or partially collapsed) due to river flooding or earthquake (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.xx]* Was there any hydraulic study done before the Design Stage?
- *[D.DE.XX]* Has the hydraulic study been considered in the structural design as a flooding load case?
- *[D.DE.XX]* Does the structural design include a seismic load case?
- *[D.DE.XX]* Is the considered seismic load case consistent with current Design Standards?

Exceedance of Structural Capacity

S.MC.XX Has the structural capacity of the elements been exceeded (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.xx]* Are Design Loads properly defined at Design Stage?
- *[D.DE.XX]* Has the load exceeded the Design Load?
- *[D.DE.XX]* Does the element have enough bending moment reinforcement in all directions ?
- *[D.DE.XX]* Does the element have adequate shear reinforcement near the abutments and diaphragms?
- *[D.DE.XX]* Does the element have adequate torsional shear reinforcement near the abutments and diaphragms?
- *[D.DE.XX]* Is the reinforcement detailing (length, diameter, position, mechanical and geometrical cover) clearly defined in the Structural Drawings and do not provide any contradictory information?
- *[D.EX.XX]* Has the structure been executed following the Design Drawings?

ROADS PATHOLOGIES

EXCESSIVE DEFORMATIONS

Note: Excessive Deformation and Scour/Wash-out shall be investigated jointly.

Improper soil compaction

S.MC.XX Is the excessive deformation visibly spread over the road cross section? (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.xx]* Has a Geotechnical Investigation Campaign and Interpretative Report been produced prior to the Design Stage?
- *[D.DE.XX]* Is the Geotechnical Investigation Campaign sufficiently extended (type and number of tests) to cover the project length?
- *[D.DE.XX]* Has the material of the embankment (gradation, void ratio, unit weight, moisture content etc.) been properly defined by the Geotechnical Team, consistent with the expected Design Load?
- *[D.DE.XX]* Has the Geotechnical Team defined the optimal 95% Modified Proctor Compaction Index or CBR value for the embankment material?
- *[D.DE.XX]* Has the correct construction machinery been selected to compact the embankment material ?
- *[D.EX.XX]* Is the embankment material properly drained before and during compaction?
- *[D.EX.XX]* Have the Embankment Technical Specifications been followed during execution of the compaction (layer thickness, humidity, compaction energy, …)?

Slope instability

S.MC.XX Is the excessive deformation visibly spread over the embankment slope (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.xx]* Has a Geotechnical Investigation Campaign and Interpretative Report been produced prior to the Design Stage?
- *[D.PL.xx]* Has a Hydrogeological Investigation Campaign and Interpretative Report been produced prior to the Design Stage?
- *[D.DE.xx]* Does slope stability have been checked at the Design Stage?
- *[D.MA.xx]* Is the angle of friction of the constructed embankment's material less than the angle of the slope?
- *[D.DE.xx]* Has any of the Standard LGED Design for embankments (embankment material, slope value, slope protection, …) been used?

SCOUR AND WASHOUT

Note: Excessive Deformation and Scour/Wash-out shall be investigated jointly.

Water erosion

S.NV.XX Is the loss of embankment material clearly visible from the scour process? (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.xx]* Has a Hydrogeological Investigation Campaign and Interpretative Report been produced prior to the Design Stage for embankments stability?
- *[D.DE.xx]* Is the embankment properly drained or protected against water erosion?
- *[D.MN.xx]* Are the embankment drainage culverts properly maintained for effective drainage and embankment protection?
- *[D.PL.xx]* Is the base/toe of the embankment far away from a water stream, pond, etc. or protected against water erosion as per LGED Embankment Standard Design?

POTHOLES

Fatigue Cracking

S.MC.04 Are there signs of visible cracks or series of interconnected cracks on the pavement surface (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.01]* Are Design Standards properly identified at the Design Stage?
- *[D.DE.33]* Is the extension and compaction of the asphalt clearly defined?
- *[D.DE.XX]* Has the material of the base-subbase (gradation, void ratio, unit weight, moisture content etc.) been properly defined by the Geotechnical Team, consistent with the expected Design Load?
- *[D.DE.XX]* Has the correct construction machinery been selected to compact the embankment material ?
- *[D.OP.7]* Is the road pavement still within its expected design life, according to the Pavement Technical Specification document?

Traffic loads

S.MC.06 How many truck loads is the road subjected to? (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.xx]* Has Traffic Studies been produced prior to the Design Stage?
- *[D.DE.XX]* Is the traffic loading calculated according to AASHTO requirements, for design consistency?
- *[D.DE.32]* Is the asphalt designed to resist the traffic design load during its design life?
- *[D.OP.xx]* Is there any evidence that traffic load exceeding the design load has occurred?
- *[D.OP.02]* Is there any evidence that significant vehicle braking forces have been transferred to the asphalt pavement?

Type and Properties of Aggregates

S.MC.XX. Has the road a proper aggregate design following standards for the expected traffic (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.01]* Are Design Standards properly identified at the Design Stage?
- *[D.DE.XX]* How consistent is the surface layer thickness throughout the paved surface (asphalt edge thickness versus centerline thickness)?
- *[D.DE.XX]* Was an aggregate base used to build the roadway?
- *[D.DE.XX]* Is the aggregate mix calculated according to AASHTO and/or the Pavement Design Catalogue of LGED?
- *[D.EX.XX]* Have the Pavement Technical Specifications been followed during execution?

Water Sources

S.NV.06 How much time does it take to properly drain the surface of the road (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.XX]* Is the road near a water source, like a river, channel…?
- *[D.PL.xx]* Has a Hydrological Investigation Campaign and Interpretative Report been produced prior to the Design Stage?
- *[D.DE.03]* Is the drainage system precisely and clearly calculated?
- *[D.DE.xx]* Is the base-subbase far away from a water stream, pond, etc. or protected against water erosion as per LGED Embankment Standard Design?
- *[D.MN.xx]* Are the drainage culverts properly maintained for effective drainage and embankment protection?

RUTTING

Traffic Loads

S.MC.06 How many truck loads is the road subjected to? (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.xx]* Has Traffic Studies been produced prior to the Design Stage?
- *[D.DE.XX]* Is the traffic loading calculated according to AASHTO requirements, for design consistency?
- *[D.DE.32]* Is the asphalt designed to resist the traffic design load during its design life?
- *[D.OP.xx]* Is there any evidence that traffic load exceeding the design load has occurred?
- *[D.OP.02]* Is there any evidence that significant vehicle braking forces have been transferred to the asphalt pavement?

Base-subbase instability

S.MC.xx Has the road deformed vertically but does NOT present lateral elevations (Type 2 Rutting) (please refer to Guidance Material for scoring assessment range)?

- *[D.DE.XX]* Is the material of the base-subbase compliant with the Pavement Design Catalogue of LGED?
- *[D.DE.XX]* Has the Geotechnical Team defined the optimal 95% Modified Proctor Compaction Index or CBR value for the base-subbase material?
- *[D.DE.XX]* Has the correct construction machinery been selected to compact the embankment material?
- *[D.EX.12]* Are the first layers of soil, composing the base and subbase of the road, compacted in all its surface?

Aggregate/Asphalt instability

S.MC.xx Has the road visible plastic deformations to the sides of the rut (Type 1 Rutting) (please refer to Guidance Material for scoring assessment range)?

- *[D.DE.XX]* Is the extension and compaction of the asphalt clearly defined?
- *[D.EX.XX]* Have the Pavement Technical Specifications been followed during execution?
- *[D.EX.XX]* How consistent is the surface layer thickness throughout the paved surface (asphalt edge thickness versus centerline thickness)?

SURFACE CRACKING

Traffic Loads

S.MC.06 How many truck loads is the road subjected to? (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.xx]* Has Traffic Studies been produced prior to the Design Stage?
- *[D.DE.XX]* Is the traffic loading calculated according to AASHTO requirements, for design consistency?
- *[D.DE.32]* Is the asphalt designed to resist the traffic design load during its design life?
- *[D.OP.xx]* Is there any evidence that traffic load exceeding the design load has occurred?
- *[D.OP.02]* Is there any evidence that significant vehicle braking forces have been transferred to the asphalt pavement?

Asphalt Aging

S.MC.xx Is the road visibly deteriorated or aged with signs of visible cracks or series of interconnected cracks (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.01]* Are Design Standards properly identified at the Design Stage?
- *[D.DE.33]* Is the extension and compaction of the asphalt clearly defined?
- *[D.DE.XX]* Has the material of the base-subbase (gradation, void ratio, unit weight, moisture content etc.) been properly defined by the Geotechnical Team, consistent with the expected Design Load?
- *[D.DE.XX]* Has the correct construction machinery been selected to compact the base-subbase material?
- *[D.OP.7]* Is the road pavement still within its expected design life, according to the Pavement Technical Specification document?

Improper Base-Subbase Soil Properties

S.MC.XX Has the road transverse cracking (please refer to Guidance Material for scoring assessment range)?

- *[D.PL.xx]* Has a Geotechnical Investigation Campaign and Interpretative Report been produced prior to the Design Stage?
- *[D.DE.XX]* Has the road been constructed over an expansive clay soil?
- *[D.DE.XX]* Has the material of the base-subbase (gradation, void ratio, unit weight, moisture content etc.) been properly defined by the Geotechnical Team, consistent with the expected Design Load?
- *[D.DE.XX]* Has the Geotechnical Team defined the optimal 95% Modified Proctor Compaction Index or CBR value for the base-subbase material?
- *[D.DE.XX]* Has the correct construction machinery been selected to compact the base-subbase material ?

Poor joint construction or location

S.MC.XX Has the road thermal/construction joints (please refer to Guidance Material for scoring assessment range)?

- *[D.DE.XX]* Are longitudinal joints locations specified in the Design Drawings?
- *[D.EX.XX]* Have construction joints been prepared to separate the different asphalt construction days?