Methodology for

Condition Assessment of Public Sector Infrastructure Assets

in Pacific Island Countries

Prepared with technical support from

Pacific Region Infrastructure Facility

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PRIF Coordination Office
c/o Asian Development Bank
Level 20, 45 Clarence Street
Sydney, NSW 2000, Australia

Phone: +61 2 8270 9444
Email: enquiries@theprif.org
Website: www.theprif.org

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Abbreviations

ACI	Asset condition index
ADB	Asian Development Bank
FPR	Functional performance rating
PCR	Physical condition rating
PRIF	Pacific Region Infrastructure Facility

Preface

The premature deterioration of infrastructure affects people's lives as a result of degraded roads, poor school facilities, outmoded health facilities, contaminated water, and unsafe wharves and airports.

Effective asset management planning in Pacific island countries is critical for the sustainable maintenance and preservation of infrastructure. Condition assessment is an integral part of asset management for those agencies responsible for infrastructure services. Such an assessment entails periodic inspection of physical assets and determining the condition of each asset.

This manual provides a practical methodology for condition assessment for public sector infrastructure assets in Pacific island countries with limited technical skills and competencies. Designed to make managing and assessing numerous physical assets easy, it provides a systematic approach to performing a condition assessment for buildings, roads, bridges, culverts, jetties, water and sewer infrastructure, and energy and telecommunications assets.

The manual also describes the criteria for an infrastructure asset's end of life; prioritizes investments into asset renewal and replacement; provides a list of unit costs for estimating capital expenditure requirements for renewal or replacement of assets; and offers valuable information for asset management operation, budget negotiation, and planning.

This manual was prepared by Shawn Otal, a professional electrical engineer and asset management expert. The author completed the manual with support from the Pacific Catastrophe Risk Assessment Facility of the Pacific Community's Geoscience, Energy and Maritime Division as well as public sector infrastructure managers in Fiji. Mr Otal is grateful to the partners of the Pacific Region Infrastructure Fund, the Pacific Community, and the Government of Fiji for their valuable guidance, inputs, and cooperation during the preparation of the publication.

It is hoped that this manual will be a valuable planning reference for national and municipal governments, development partners, and other asset management practitioners operating in Pacific island countries and beyond.

Glossary

Asset	An item, thing, or entity that has potential or actual value to an organization (such as plant, machinery, buildings, etc.)
Asset components	Specific parts of an asset with independent physical or functional identity and specific attributes such as different life expectancy, maintenance regimes, risk, or criticality.
Asset management	The systematic and coordinated activities and practices of an organization to optimally and sustainably deliver on its objectives through cost-effective lifecycle management of assets.
Asset management plan	Long-term plans (usually 10–20 years or more for infrastructure assets) that outline the asset activities and programs for each service area and resources applied to provide a defined level of service in the most cost effective way.
Asset register	A record of asset information, typically held in a spreadsheet, database, or software system, including asset attribute data such as quantity, type, and construction cost.
Asset condition assessment	The inspection, assessment, measurement, and interpretation of the resultant data to indicate the condition of a specific component to determine the need for preventative or remedial action.
Asset condition index	An asset condition index (ACI) represents the overall operating condition rating of an infrastructure asset. For an asset, the ACI is calculated by considering the physical condition rating of its components and/or the overall functional performance rating (FPR) of the asset. In this document, ACI is represented on a scale of 1 to 100, where 1 represents an asset in very poor condition and 100 represents an asset in excellent condition
Capital expenditure	Expenditure used to create new assets, renew assets, expand or upgrade assets or to increase the capacity of existing assets beyond their original design capacity or service potential. Capital expenditure increases the value of asset stock.
Condition rating	A measure of the physical condition of an asset or asset's components.
Current service life	The elapsed time, in years, since an asset was placed in service.
End of life	An asset is deemed to have reached its end of life, when its operating condition has degraded to an unacceptable level and it cannot be restored through asset renewal, requiring the asset to be retired from service and replaced with a new asset.
Functional performance rating	The functional performance rating of an infrastructure asset represents the degree of its ability to deliver intended functional performance. FPR is determined through evaluation of the recent service performance of an asset. This document employs five functional performance ratings for infrastructure assets, ranging from 1 to 5, where 5 represents an asset providing excellent performance and 1 an asset providing very poor performance.
Gross replacement cost	It is the current replacement cost of an asset. It is the estimated capital expenditure which would be required if an existing asset is to be replaced with a new asset of the same capacity and same specification during the current year.

Level of service	The parameters or combination of parameters that reflect social, political, economic, and environmental outcomes that the organization delivers. Levels of service statements describe the outputs or objectives an organization or activity intends to deliver to customers.
Lifecycle	The time interval that commences with the identification of the need for an asset and terminates with the decommissioning of the asset or any liabilities thereafter.
Maintenance	All actions necessary for retaining an asset as near as practicable to its original condition but excluding rehabilitation or renewal. Maintenance does not increase the service potential of the asset or keeps it in its original condition, it slows deterioration and delays rehabilitation or replacement need.
Operating expenditure	Operating expenditure is the annually recurring expenditure required for safe and reliable operation of assets. Maintenance and minor repairs are examples of operating expenditure. The benefits of operating expenditure are deemed to be consumed during the same year in which they are incurred, and such expenditure events are not recorded in the asset register.
Performance rating	A measure of the ability of the asset to achieve levels of service.
Physical condition rating	The physical condition rating (PCR) of an infrastructure asset component represents its current operating condition. It is determined through asset condition assessment. This document employs five ranks to represent PCRs for infrastructure assets' components, from 1 to 5, where 5 represents an asset in excellent physical condition and 1 an asset in very poor condition.
Planned maintenance	Planned maintenance activities fall into three categories: (i) periodic—necessary to ensure the reliability or to sustain the design of an asset; (ii) predictive—condition monitoring activities used to predict failure; (iii) preventative—maintenance that can be initiated without routine or continuous checking (e.g., using information contained in maintenance manuals or manufacturers' recommendations) and is not condition based.
Rehabilitation (refurbish)	Works to rebuild or replace parts or components of an asset, to restore it to a required functional condition, and extend its life, which may incorporate some modification, generally involves repairing the asset to deliver its original level of service (i.e., heavy patching of roads, slip-lining of sewer mains, etc.) without resorting to significant upgrading or renewal, using available techniques and standards.
Remaining useful life	Remaining useful life of an asset is the estimated time in years during which an asset is expected to continue providing acceptable functional performance before requiring replacement.
Renewal	Works to replace existing assets or facilities with assets or facilities of equivalent capacity or performance capability.
Replacement	The complete replacement of an asset that has reached the end of its life so as to provide similar or an agreed alternative level of service
Typical useful life	Typical useful life of an asset or asset component is the estimated or expected time in years during which an asset or asset component is expected to provide acceptable functional performance before requiring replacement, when recommended maintenance is performed.


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1. Introduction

The condition and operating performance of all infrastructure assets gradually degrade. The reasons for this degradation include:

(i) gradual wear and tear, corrosion or erosion, deformation, or other physical or chemical changes in an asset's components;

(ii) damaged or defective parts within components;

(iii) increase in frictional forces due to drying of lubricants, elevated operating temperature due to low levels of coolants, or increase in vibrations (in the case of assets with moving parts); and

(iv) lack of preventative maintenance resulting in premature asset impairment.

In addition to gradual degradation, infrastructure assets can also suffer damage or sudden failure caused by accidents or natural disasters.

The degradation in physical condition of an asset's components directly impacts its ability to deliver its intended operating performance safely and reliably.

The typical useful life of an infrastructure asset or asset component is the period during which the asset or asset component is expected to provide functional performance within an acceptable range, under typical environmental conditions and the recommended maintenance regime. An asset is deemed to have reached its end of life when its operating performance falls below the lowest acceptable service level.

An infrastructure asset's typical useful life can be defined based on historical experience. Therefore, for all assets, a rough estimate of the remaining useful life can be made by subtracting the asset's current service life from its typical useful life.

The actual service life of an asset, or one of its components, can deviate significantly from the expected useful life, depending on the environment in which it operates and the maintenance it receives, or because of impairment due to an accident or natural disaster. As a result, some assets fail prematurely—sometimes long before they reach their typical useful life—while others continue to provide reliable service for many years beyond their useful life.

1.1 The Importance of Methodical Asset Assessment

Instead of determining the end of life of an asset based on its typical useful life, modern asset management practices dictate that decisions on, and investments into, an asset's renewal or replacement be based on assessment of the asset's operating condition rather than its service age.

This manual provides a systematic approach and methodology to assess the operational condition of public sector infrastructure assets, particularly those found in Pacific island countries. The asset condition assessment methodology is designed to be practical and relatively simple, so it can be applied in countries with limited technical skills and competencies.

The manual provides a condition assessment methodology for the following types of infrastructure assets:

- buildings
- roads
- bridges and culverts
- wharves and jetties
- coastal protection
- water and sewer infrastructure
- electricity infrastructure
- telecommunications infrastructure

The manual is organized into 13 sections, including this introduction.

Section 2 describes the general methodology for assessing the condition of infrastructure assets and for expressing the results in the form of an asset condition index. This section also describes the criteria for an infrastructure asset's end of life and prioritization of investments into renewal and replacement.

Section 3 lists the recommended algorithms to quantitatively express the condition of infrastructure assets in the form of the asset condition index.

Section 4 outlines unit costs for estimating capital expenditure on renewing or replacing infrastructure assets.

Sections 5 to 13 detail the condition assessment methodology applicable to specific infrastructure asset categories, under the following headings:

(i) main components of assets, their functions, and typical useful life;

(ii) typical degradation modes and their impact on functional performance;

(iii) condition assessment techniques;

(iv) recommendations for maintenance; and

(v) data collection requirements to effectively manage the assets.

The methodology provided is helpful in achieving the following asset management tasks:

(i) identifying the pertinent information to be collected and analyzed to accurately assess an infrastructure asset's condition;

(ii) ranking the existing condition of individual assets, or determining the average condition of all assets in a service sector and comparing it to the average condition of assets in other service sectors;

(iii) correlating the condition of assets to their service age;

(iv) establishing what percentage of infrastructure assets in a service sector needs investment to achieve a satisfactory operating condition; and

(v) determining the optimal level and timing of investments required for asset renewal or replacement.

2. Methodology for Asset Condition Assessment

International asset management standards require the use of a quantitative scale to express, rank, compare, and benchmark the operating condition of infrastructure assets. Accordingly, the methodology provided in this manual proposes the use of the asset condition index (ACI).

The index describes the ability of an asset to meet its intended operating performance safely and reliably, expressed on a numeric scale of 1 to 100. When the ACI for an asset reaches an unacceptable level, the asset is deemed to have reached its end of life and must be retired from service and replaced.

To obtain accurate results within the ACI, it is vital that all asset condition assessments be performed by a competent person, i.e., a building inspector for buildings, a road inspector for roads and bridges, or a line foreman for power lines, etc. This person should have the required technical skills to evaluate and rank the physical condition of major components. For most assets, a foreman with 5–10 years of general maintenance experience for that asset category would be considered competent to carry out condition assessment.

There are two approaches that can be utilized to assess the condition of an infrastructure asset and express the results on a numeric scale under the ACI. The first approach is based on determining the ACI based solely on assessing the physical condition of the asset at the component level. The second approach combines each asset component's physical condition rating with an asset functional performance rating to improve the results of condition assessment.

2.1 Using Component Physical Condition Ratings Only

Most infrastructure assets are composed of multiple components, the physical condition of which impacts the assets' overall performance.

For example, a building's components include substructure (foundation); superstructure (pillars, load bearing walls, floor joists, roof trusses); building envelope (wall cladding, roof covering); interior finishes (ceilings, floors, interior wall finishes, kitchen cabinetry, etc.); and services (electrical, mechanical, plumbing, etc.). Similarly, a road's components include formation (earthworks), base pavement, surface seal, curbing and guttering, and drainage sumps.

The condition assessment of infrastructure assets should be performed at the component level. The flow chart in Figure 2-1 summarizes the main steps in this process, followed by a step-by-step implementation process.

Figure 2-1: Decision-Making Process Based on Component Condition Only

STEP 1	Perform condition assessment to determine PCR of asset components (use Table 2-1 for ratings)
STEP 2	Calculate asset condition index (use appropriate table for the asset ACI algorithm from section 3)
STEP 3	Assess the risk of failure and estimate the remaining useful life of asset (use Table 2-3)
STEP 4	Select the optimal investment option (use Table 2-4)

ACI = asset condition index, PCR = physical condition rating.

STEP 1: Determine the Physical Condition Rating of Asset Components

Using the criteria summarized in Table 2-1, assign each component a physical condition rating based on its current operating state. These ratings range from 1 to 5, where 5 represents excellent condition and 1 represents very poor condition.

During preliminary screening, the component may be assessed based on visual inspection only and, for those components found in less than satisfactory condition, detailed investigations should be performed to confirm if they should be ranked as being in fair, poor, or very poor condition.

Assign the rating for an asset component's physical condition by considering all available information related to the component's operating condition, collected through:

(i) visual inspection and site measurement to identify degree of defects, deterioration, or damage to an asset or its components;

(ii) in-situ, nondestructive testing of infrastructure assets to determine the remaining strength of the asset or asset components;

(iii) lab testing of asset samples to determine their remaining strength; and

(iv) engineering analysis (calculations) to establish the structural strength of the asset's components in relation to actual and/or expected structural loading.

Table 2-1: Asset Component Physical Condition Ratings

Asset Component Condition	Physical Condition Rating	Interpretation
Asset component in brand new condition, with no wear, no damage, no deformation, no defects, no deterioration, no impairment.	5	Excellent
Asset component in "like new" condition, with minor wear and no damage, no defects, no deformation, no deterioration, and no impairment.	4	Good
Asset component shows minor wear, minor deformation, minor damage, minor defects, minor deterioration, minor impairment, asset condition can be maintained through normal preventative maintenance.	3	Fair
Asset component with major deformation, degradation, deterioration, damage or defects and serious impairment in condition; however component condition can be restored through economically efficient rehabilitation/refurbishment of degraded/ faulty components.	2	Poor
Asset component with major degradation, deterioration, damage or defects and serious impairment in condition, and it is not possible to restore the component condition through economically efficient rehabilitation/refurbishment.	1	Very poor

It is noteworthy that the component ratings used in this manual are the opposite of the rating system suggested in the International Infrastructure Management Manual. The system proposed here is more convenient because it allows calculation of the ACI on a scale of 100, without the need to transpose component ratings.

Step 2: Calculate the Asset Condition Index

Under this approach, the physical condition ratings of an asset's major components are given a range of weightings. These weights are based on the importance of the role different component's play in an asset's functional performance (the cost of component renewal as a proportion of the total replacement cost is also considered).

Table 2-2 illustrates the composition of a typical ACI algorithm based on this approach, using buildings as an example.

To calculate the ACI, start by multiplying each component's weight by its physical condition rating (as assigned in Step 1). This gives you an "actual score" for each component. Next, add together the results for every component to obtain the "total actual score". Now, divide the total actual score by the total maximum score and multiply by 100 to obtain the ACI (expressed on a common scale of 1 to 100 for all assets).

Note that, in the standardized ACI algorithms, some assets may not have all their components listed. In such cases, the missing component should be omitted, with both the maximum and actual score for that component set to zero.

Table 2-2: Building Assessed on Component Condition Only

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Asset component physical condition	Substructure	3	1,2,3,4,5	15	
	Superstructure	5	1,2,3,4,5	25	
	Building envelope	2	1,2,3,4,5	10	
	Interior finishes	2	1,2,3,4,5	10	
	Services	2	1,2,3,4,5	10	
Total score		14		70	
Asset condition index = (actual score/maximum score) x 100					

Note: ACI = asset condition index.

ACI algorithms (based on component condition assessment) for all assets covered by this manual are documented in Section 3.

Step 3: Estimate Remaining Useful Life and Risk of Failure

The value of the ACI calculated in Step 2 can be directly applied to estimate an asset's remaining useful life and to interpret the risk of it failing in service.

In Table 2-3, the estimate of an asset's remaining useful life is expressed as a percentage of its typical useful life (the typical useful lives of all infrastructure assets covered by this manual are discussed in sections 5–13). The table also estimates the risk of the asset failing in service, from "very high" to "very low".

Table 2-3: Risk Assessment and Remaining Useful Life Estimate

Asset Condition Index	Interpretation	Remaining Useful Life	Risk of Failure in Service
0 to 20	Very Poor	<5% of its TUL	Very High
21 to 40	Poor	<20% and ≥5% of its TUL	High
41 to 60	Fair	<50% and ≥20% of its TUL	Moderate
61 to 80	Good	<85% and ≥50% of its TUL	Low
81 to 100	Excellent	≥85% of its TUL	Very Low

Note: TUL = typical useful life.

STEP 4: Determine Optimal Investment Option

Using Table 2-4, the value of an asset's ACI (as calculated in Step 2) can be applied to determine the optimal investment option.

Table 2-4: Determining Optimal Investment Option

Asset or Component Condition	Recommended Action for Investment Planning
ACI = 0 to 20	Plan asset replacement - with high priority
ACI = 21 to 40	Plan asset replacement
ACI >40, but one or more component's Rating 2 or Less	Plan renewal of components with condition rating of 2 or Less
ACI >40 and all components with rating of 3 or higher	Only scheduled maintenance and inspections are required

Note: ACI = asset condition index

2.2 Using Both Component Physical Condition and Asset Functional Performance Ratings

In addition to physical condition ratings, which are assessed at the component level, the overall functional performance of an asset is assessed by evaluating the output it produces.

To measure an asset's functional performance, most public sector organizations have established service levels as acceptable performance benchmarks, against which actual performance should be measured and compared. The service levels are set as an acceptable range and they commonly include the relevant performance indicators to express:

- quality and quantity of service provided by the asset;
- reliability of service provided by the asset, i.e., frequency and duration of service interruptions;
- the safety impacts of asset operation; and
- the operating efficiency of the asset, determined by monitoring maintenance and emergency repair costs, etc.

The flow chart in Figure 2-2 shows how including the functional performance rating changes the second approach into a five-step process (note that steps 1, 4, and 5 are the same as in the first approach).

Figure 2-2: Decision-Making Process Based on Component Condition and Asset Performance

STEP 1	Perform condition assessment to determine PCR of asset components (use Table 2-1 for ratings)
STEP 2 A	Establish FPR of asset by assessing recent asset performance (use Table 2-5 for ratings)
STEP 2 B	Calculate asset condition index (use appropriate table for the asset ACI algorithm from section 3)
STEP 3	Assess the risk of failure and estimate the remaining useful life of asset (use Table 2-3)
STEP 4	Select the optimal investment option (use Table 2-4)

Note: ACI = asset condition index, FPR = functional performance rating, PCR = physical condition rating.

Step 1: Determine the Physical Condition Rating of Asset Components

Follow the same process as described in Step 1 of Section 2.1.

Step 2: Assign the Asset's Functional Performance Rating

An asset's functional performance rating is expressed as one of five distinct performance states, ranging from 1 to 5, where 5 represents excellent performance and 1 represents very poor performance.

Table 2-5 indicates the recommended criteria for ranking an asset's functional performance. Consider the current output of your asset in relation to desired service levels to assign its functional performance rating.

Table 2-5: Asset Functional Performance Ratings

Asset Functional Performance Rating	Condition Score	Interpretation
Asset's functional performance exceeds the upper limit of the desired service levels.	5	Excellent
Asset's functional performance meets the upper limit of the desired service levels.	4	Good
Asset's functional performance meets the lower limit of the service level requirements.	3	Fair
Asset's functional performance does not meet the lower limit of the service level requirements, however through refurbishment/renewal it is possible to restore the performance to acceptable level.	2	Poor
Asset's functional performance does not meet the lower limit of the service level requirements, and it is not possible to restore the performance to acceptable levels through renewal/refurbishment.	1	Very poor

Step 3: Calculate the Asset Condition Index

In this approach, an extra step is added to the calculation of the ACI to account for the asset's functional performance rating.

Table 2-6 illustrates the composition of a typical ACI algorithm based on this approach, using buildings as an example.

To calculate the ACI, start by multiplying each component's weight by its physical condition rating (as assigned in Step 1). This gives you an "actual score" for each component. Next, multiply the asset's functional performance weight by its functional performance rating (as assigned in Step 2). This gives you an actual score for asset functional performance. Now, add together the actual scores for every component and the actual score for asset functional performance. Divide the total actual score by the total maximum score and multiply by 100 to obtain the ACI (expressed on a common scale of 1 to 100 for all assets).

Table 2-6: Building Assessed on Component Condition and Asset Performance

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Component Physical Condition	Substructure	3	1,2,3,4,5	15	
	Superstructure	5	1,2,3,4,5	25	
	Building envelope	2	1,2,3,4,5	10	
	Interior finishes	2	1,2,3,4,5	10	
	Services	2	1,2,3,4,5	10	
Asset Functional Performance		4	1,2,3,4,5	20	
Total score		18		90	
Asset condition index = (actual score/maximum score) x 100					

ACI algorithms (based on component physical condition and asset functional performance) for all assets covered by this manual are documented in section 3.

Step 4: Estimate Remaining Useful Life and Risk of Failure

Apply the ACI calculated in Step 3 to Table 2-3 in Section 2.1.

Step 5: Determine Optimal Investment Option

Apply the ACI calculated in Step 3 to Table 2-4 in Section 2.1.

Example:

The following example illustrates the calculation of the ACI for a building, as well as how the ACI can be interpreted and applied. The asset is a media broadcast building in the Yaren District of Nauru. The following information was collected through inspections performed in 2019.

Asset information

Service sector: Information and communication technology
Asset category: Media building
Asset location: Yaren District, Nauru
Asset type: Single story, masonry and concrete, standard design
Asset dimensions: Floor area of 290 square meters
Year of construction: 1972

Component types and subtypes

Substructure:	Concrete slab and concrete foundation wall
Building structure:	Steel reinforced concrete walls and steel-reinforced concrete roof
Building envelope:	Steel reinforced walls and steel-reinforced roof
Interior finishes:	Plasterboard ceilings and wall finishes, vinyl flooring.
Services:	Below-grade water tank with rain harvesting, two-compartment septic tank, electric mains with generator backup, wall-mounted air conditioners

Component physical condition ratings

Substructure:	3
Superstructure:	1 (Water has been entering the concrete roof and walls for many years; the rebar is badly rusted, and severe concrete spalling has exposed the rebar in several locations. A structural engineer has evaluated and confirmed the building structure is unsafe).
Building envelope:	2 (Roof and walls are degraded and do not effectively block moisture from entering the building interior during rainfall).
Interior finishes:	2 (There is visible damage to the plaster ceiling and plaster walls in several locations).
Services:	2 (Moisture ingress into electrical wiring has degraded it, air-conditioning units are badly rusted).

Asset Functional Performance rating:
2 (during the rainy season, water is continually dripping from ceilings, affecting the quality of shelter provided by the building to communication equipment and building occupants).

By using the parameters in Table 2-7, the ACI has been calculated as 37.8. By referring back to Table 2-3, this asset is determined to be in poor condition and, applying the criteria of Table 2-4, the optimal investment option is to plan for asset renewal or replacement.

Table 2-7: Demonstration of Actual Scores and Asset Condition Index Calculation

<table>
<tr><th colspan="2">Condition Criteria</th><th>Weight</th><th>Condition Ratings</th><th>Maximum Score</th><th>Actual Score</th></tr>
<tr><td rowspan="5">Component Physical Condition</td><td>Substructure</td><td>3</td><td>3</td><td>15</td><td>9</td></tr>
<tr><td>Superstructure</td><td>5</td><td>1</td><td>25</td><td>5</td></tr>
<tr><td>Building envelope</td><td>2</td><td>2</td><td>10</td><td>4</td></tr>
<tr><td>Interior finishes</td><td>2</td><td>2</td><td>10</td><td>4</td></tr>
<tr><td>Services</td><td>2</td><td>2</td><td>10</td><td>4</td></tr>
<tr><td colspan="2">Asset Functional Performance</td><td>4</td><td>2</td><td>20</td><td>8</td></tr>
<tr><td colspan="2">Total score</td><td>18</td><td></td><td>90</td><td>34</td></tr>
<tr><td colspan="5">Asset condition index = (actual score/maximum score) x 100</td><td>37.8</td></tr>
</table>

3. Asset Condition Assessment Algorithms

In this section, two ACI algorithms are presented for each type of infrastructure asset covered by this manual. The first algorithm is based solely on the physical condition ratings of an asset's components, and this may be employed when information on the asset's functional performance is not readily available. The second algorithm takes into account the overall functional performance of the asset as well as the physical condition of its individual components.

3.1 Buildings

Table 3-1: Building Assessed on Component Condition Only

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Asset component physical condition	Substructure	3	1,2,3,4,5	15	
	Superstructure	5	1,2,3,4,5	25	
	Building envelope	2	1,2,3,4,5	10	
	Interior finishes	2	1,2,3,4,5	10	
	Services	2	1,2,3,4,5	10	
Total score		14		70	
Asset condition index = (actual score/maximum score) x 100					

Table 3-2: Building Assessed on Component Condition and Asset Performance

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Component Physical Condition	Substructure	3	1,2,3,4,5	15	
	Superstructure	5	1,2,3,4,5	25	
	Building envelope	2	1,2,3,4,5	10	
	Interior finishes	2	1,2,3,4,5	10	
	Services	2	1,2,3,4,5	10	
Asset Functional Performance		4	1,2,3,4,5	20	
Total score		18		90	
Asset condition index = (actual score/maximum score) x 100					

3.2 Roads

Table 3-3: Sealed Road Assessed on Component Condition Only

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Asset component physical condition	Pavement base course	4	1,2,3,4,5	20	
	Surface seal	4	1,2,3,4,5	20	
	Curb and gutter	1	1,2,3,4,5	5	
	Drainage system	1	1,2,3,4,5	5	
Total score		10		50	
Asset condition index = (actual score/maximum score) x 100					

Table 3-4: Sealed Road Assessed on Component Condition and Asset Performance

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Component Physical Condition	Pavement base course	4	1,2,3,4,5	20	
	Surface seal	4	1,2,3,4,5	20	
	Curb and gutter	1	1,2,3,4,5	5	
	Drainage system	1	1,2,3,4,5	5	
Asset Functional Performance		4	1,2,3,4,5	20	
Total score		14		70	
Asset condition index = (actual score/maximum score) x 100					

Table 3-5: Unsealed Road or Footpath Assessed on Component Condition Only

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Asset component physical condition	Pavement	8	1,2,3,4,5	40	
Total score		8		40	
Asset condition index = (actual score/maximum score) x 100					

Table 3-6: Unsealed Road or Footpath Assessed on Component Condition and Asset Performance

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Component Physical Condition	Pavement	8	1,2,3,4,5	40	
Asset Functional Performance		4	1,2,3,4,5	20	
Total score		12		60	
Asset condition index = (actual score/maximum score) x 100					

3.3 Bridges and Culverts

Table 3-7: Bridge Assessed on Component Condition Only

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Asset component physical condition	Substructure	3	1,2,3,4,5	15	
	Superstructure	3	1,2,3,4,5	15	
	Decking	3	1,2,3,4,5	15	
Total score		9		45	
Asset condition index = (actual score/maximum score) x 100					

Table 3-8: Bridge Assessed on Component Condition and Asset Performance

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Component Physical Condition	Substructure	3	1,2,3,4,5	15	
	Superstructure	3	1,2,3,4,5	15	
	Decking	3	1,2,3,4,5	15	
Asset Functional Performance		3	1,2,3,4,5	15	
Total score		12		60	
Asset condition index = (actual score/maximum score) x 100					

Table 3-9: Culvert Assessed on Component Condition Only

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	6	1,2,3,4,5	30	
Total score	6		30	
Asset condition index = (actual score/maximum score) x 100				

Table 3-10: Culvert Assessed on Component Condition and Asset Performance

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical Condition	6	1,2,3,4,5	30	
Asset Functional Performance	4	1,2,3,4,5	20	
Total score	10		50	
Asset condition index = (actual score/maximum score) x 100				

3.4 Airport Runways and Taxiways

Table 3-11: Runway or Taxiway Assessed on Component Condition Only

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Asset component physical condition	Base pavement	2	1,2,3,4,5	10	
	Surface pavement	4	1,2,3,4,5	20	
Total score		6		30	
Asset condition index = (actual score/maximum score) x 100					

Table 3-12: Runway or Taxiway Assessed on Component Condition and Asset Performance

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Component Physical Condition	Base pavement	2	1,2,3,4,5	10	
	Surface pavement	4	1,2,3,4,5	20	
Asset Functional Performance		4	1,2,3,4,5	20	
Total score		10		50	
Asset condition index = (actual score/maximum score) x 100					

3.5 Wharfs and Jetties

Table 3-13: Wharf or Jetty Assessed on Component Condition Only

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Asset component physical condition	Structure	6	1,2,3,4,5	30	
	Decking	4	1,2,3,4,5	20	
Total score		10		50	
Asset condition index = (actual score/maximum score) x 100					

Table 3-14: Wharf or Jetty Assessed on Component Condition and Asset Performance

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Component Physical Condition	Structure	6	1,2,3,4,5	30	
	Decking	4	1,2,3,4,5	20	
Asset Functional Performance		4	1,2,3,4,5	15	
Total score		13		65	
Asset condition index = (actual score/maximum score) x 100					

3.6 Coastal Protection

Table 3-15: Coastal Protection Structure Assessed on Component Condition Only

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	6	1,2,3,4,5	30	
Total score	6		30	
Asset condition index = (actual score/maximum score) x 100				

Table 3-16: Coastal Protection Structure Assessed on Component Condition and Asset Performance

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical Condition	6	1,2,3,4,5	30	
Asset Functional Performance	2	1,2,3,4,5	10	
Total score	8		40	
Asset condition index = (actual score/maximum score) x 100				

3.7 Water and Sanitation Assets

Table 3-17: Water Desalination Plant or Pumping Station Assessed on Component Condition Only

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	3	1,2,3,4,5	15	
Total score	3		15	
Asset condition index = (actual score/maximum score) x 100				

Table 3-18: Water Desalination Plant or Pumping Station Assessed on Component Condition and Asset Performance

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical Condition	3	1,2,3,4,5	15	
Asset Functional Performance	6	1,2,3,4,5	30	
Total score	9		45	
Asset condition index = (actual score/maximum score) x 100				

Table 3-19: Water Storage Tank or Rain Harvesting System Assessed on Component Condition Only

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	5	1,2,3,4,5	25	
Total score	5		25	
Asset condition index = (actual score/maximum score) x 100				

Table 3-20: Water Storage Tank or Rain Harvesting System Assessed on Component Condition and Asset Performance

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical Condition	5	1,2,3,4,5	25	
Asset Functional Performance	5	1,2,3,4,5	25	
Total score	10		50	
Asset condition index = (actual score/maximum score) x 100				

Table 3-21: Water Distribution or Sewer Collection Pipe Assessed on Component Condition Only

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	2	1,2,3,4,5	10	
Total score	2		10	
Asset condition index = (actual score/maximum score) x 100				

Table 3-22: Water Distribution or Sewer Collection Pipe Assessed on Component Condition and Asset Performance

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical Condition	2	1,2,3,4,5	10	
Asset Functional Performance	8	1,2,3,4,5	40	
Total score	10		50	
Asset condition index = (actual score/maximum score) x 100				

Table 3-23: Water or Sewer Manhole Assessed on Component Condition Only

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	6	1,2,3,4,5	30	
Total score	6		30	
Asset condition index = (actual score/maximum score) x 100				

Table 3-24: Water or Sewer Manhole Assessed on Component Condition and Asset Performance

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical Condition	6	1,2,3,4,5	30	
Asset Functional Performance	3	1,2,3,4,5	15	
Total score	9		45	
Asset condition index = (actual score/maximum score) x 100				

3.8 Electricity Generating and Distribution Assets

Table 3-25: Diesel Generator Assessed on Component Condition Only

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	Prime mover	6	1,2,3,4,5	30	
	Alternator	4	1,2,3,4,5	20	
Total score				50	
Remaining Service Potential = (actual score/maximum score) x 100					

Table 3-26: Diesel Generator Assessed on Component Condition and Asset Performance

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Component Physical Condition	Prime mover	6	1,2,3,4,5	30	
	Alternator	4	1,2,3,4,5	20	
Asset Functional Performance		4	1,2,3,4,5	20	
Total score				70	
Remaining Service Potential = (actual score/maximum score) x 100					

Table 3-27: Solar-Power-Generating Plant Assessed on Component Condition Only

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	Solar array	6	1,2,3,4,5	30	
	Inverter	4	1,2,3,4,5	20	
Total score				50	
Remaining Service Potential = (actual score/maximum score) x 100					

Table 3-28: Solar-Power-Generating Plant Assessed on Component Condition and Asset Performance

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Component Physical Condition	Solar array	6	1,2,3,4,5	30	
	Inverter	4	1,2,3,4,5	20	
Asset Functional Performance		4	1,2,3,4,5	20	
Total score				70	
Remaining Service Potential = (actual score/maximum score) x 100					

Table 3-29: Overhead Distribution Line Assessed on Component Condition Only

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	Poles and crossarms	6	1,2,3,4,5	30	
	Conductors and insulators	4	1,2,3,4,5	20	
Total score				50	
Asset condition index = (actual score/maximum score) x 100					

Table 3-30: Overhead Distribution Line Assessed on Component Condition and Asset Performance

Condition Criteria		Weight	Condition Ratings	Maximum Score	Actual Score
Component Physical Condition	Poles and crossarms	6	1,2,3,4,5	30	
	Conductors and insulators	4	1,2,3,4,5	20	
Asset Functional Performance		4	1,2,3,4,5	20	
Total score				70	
Asset condition index = (actual score/maximum score) x 100					

Table 3-31: Underground Cable Assessed on Component Condition Only

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	2	1,2,3,4,5	10	
Total score	2		10	
Asset condition index = (actual score/maximum score) x 100				

Table 3-32: Underground Cable Assessed on Component Condition and Asset Performance

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical Condition	2	1,2,3,4,5	10	
Asset Functional Performance	8	1,2,3,4,5	40	
Total score	10		50	
Asset condition index = (actual score/maximum score) x 100				

Table 3-33: Distribution Transformer Assessed on Component Condition Only

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	5	1,2,3,4,5	25	
Total score	5		25	
Asset condition index = (actual score/maximum score) x 100				

Table 3-34: Distribution Transformer Assessed on Component Condition and Asset Performance

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical Condition	5	1,2,3,4,5	25	
Asset Functional Performance	5	1,2,3,4,5	25	
Total score	10		50	
Asset condition index = (actual score/maximum score) x 100				

Table 3-35: Power Switchgear Assessed on Component Condition Only

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	4	1,2,3,4,5	20	
Total score	4		20	
Asset condition index = (actual score/maximum score) x 100				

Table 3-36: Power Switchgear Assessed on Component Condition and Asset Performance

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical Condition	4	1,2,3,4,5	20	
Asset Functional Performance	8	1,2,3,4,5	40	
Total score	12		60	
Asset condition index = (actual score/maximum score) x 100				

3.9 Telecommunication Assets

Table 3-37: Antenna Tower Assessed on Component Condition Only

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	6	1,2,3,4,5	30	
Total score	6		30	
Asset condition index = (actual score/maximum score) x 100				

Table 3-38: Antenna Tower Assessed on Component Condition and Asset Performance

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical Condition	6	1,2,3,4,5	30	
Asset Functional Performance	2	1,2,3,4,5	10	
Total score	8		40	
Asset condition index = (actual score/maximum score) x 100				

Table 3-39: Telecom Cable Assessed on Component Condition Only

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	2	1,2,3,4,5	10	
Total score	2		10	
Asset condition index = (actual score/maximum score) x 100				


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FIJI

Table 3-40: Telecom Cable Assessed on Component Condition and Asset Performance

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical Condition	2	1,2,3,4,5	10	
Asset Functional Performance	8	1,2,3,4,5	40	
Total score	10		50	
Asset condition index = (actual score/maximum score) x 100				

Table 3-41: Indoor Units or Outdoor Units Assessed on Component Condition Only

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical condition	4	1,2,3,4,5	20	
Total score	4		20	
Asset condition index = (actual score/maximum score) x 100				

Table 3-42: Indoor Units or Outdoor Units Assessed on Component Condition and Asset Performance

Condition Criteria	Weight	Condition Ratings	Maximum Score	Actual Score
Physical Condition	4	1,2,3,4,5	20	
Asset Functional Performance	6	1,2,3,4,5	30	
Total score	10		50	
Asset condition index = (actual score/maximum score) x 100				

Detailed information to support these algorithms—including descriptions of the main components of different infrastructure assets, their degradation modes, and condition assessment techniques—as well as the recommended maintenance practices to prevent premature impairment of assets, is provided in sections 5 to 13.

4. Estimating Asset Replacement and Renewal Cost

This section documents the "per-unit" construction costs in Pacific Island countries, which can be used to estimate asset replacement or component renewal costs.

Notably, the per-unit construction costs for infrastructure can vary over a broad range depending on the complexity of design; quality of materials; and whether the required skills and competencies are available locally, allowing a local contractor to be engaged for the project, or if a foreign contractor with foreign workers needs to be retained. As such, the costs indicated in this manual are only approximate and actual costs can vary significantly from the indicated units.

The unit costs for buildings, roads, footpaths, runways, and coastal protection should be considered of class 3 accuracy (-20%, +30%), suitable for preparing pre-design budgets. For the remaining infrastructure assets, including bridges and culverts, wharfs and jetties, electricity, telecommunications, water and sewer services, the designs employed for infrastructure construction are extremely site specific, with significant diversity and variation in equipment specifications and ratings. For these assets, the per unit estimate provided in this document should be considered class 5 accuracy (-50% to +100%). To obtain more accurate information for estimating construction costs of specific infrastructure assets, public sector departments and utilities should be contacted.

Unit-prices for infrastructure construction also vary significantly from one country to another depending on the applicable freight costs, determined by distances and connectivity with major international ports as well as by market size. The unit prices provided in this document are the estimated construction costs in Fiji. A separate table, indicating an appropriate multiplier, is provided to allow adjustment of the unit prices to any other Pacific countries.

The unit prices provided in this document are in 2019 US dollars. To develop cost estimates for asset renewal or replacement during years after 2019, the unit costs provided in this document should be adjusted for inflation.

The costs include material, labor, engineering, and administration costs for project procurement and construction, but do not include the cost of land and customs and excise duties.

4.1 Buildings

For estimating building construction costs for public sector enterprises, the buildings can be divided into three categories:

(i) basic design, one story, non-engineered buildings, timber framing, standard height, including pre-assembled trailer buildings;

(ii) standard construction, one or two-story, engineered buildings (steel or wood framing) with standard fit-outs; and

(iii) superior construction, high ceiling height, or multi-story, engineered buildings (reinforced concrete) with superior fit-outs

Based on the recent construction costs of public sector buildings in Pacific countries, the per-unit replacement cost for each category of buildings and the renewal cost of their components, not including the cost of land, are shown in Table 4-1.

The unit costs in Table 4-1 are based on the following references:

- iBuild kit homes indicative price[1]
- Tuvalu asset management framework
- Nauru Asset Management Framework
- Average cost of construction in Australia[2]
- Canadian Construction Cost Guide—Atlus Group[3]
- Feedback from Ministry of Infrastructure and Transport—Work Study Unit

Table 4-1: Per-Unit Building Construction Costs

	Units of Measurement	Per Unit Cost (GRC) in 2019 $		
Building Components	**Floor Area (Exterior)**	**Basic Design**	**Standard Design**	**Superior Design**
Substructure	m^2	165	250	375
Structure	m^2	330	500	750
Roofing	m^2	80	120	180
Exterior wall cladding	m^2	55	80	120
Fitouts	m^2	200	300	450
Floor covering	m^2	35	50	65
Service mechanical	m^2	20	25	30
Services electrical	m^2	80	100	150
Services sanitation	m^2	20	25	30
Services water	m^2	20	25	30
Total building replacement	**m^2**	**1005**	**1475**	**2180**

Note: m^2 = square meter, GRC= Gross replacement cost.

These per unit costs should be multiplied with a country specific correction factor, indicated in Table 4-2, to adjust the prices for any of the Pacific Island countries.

Table 4-2: Country Specific Correction Factors for Building Construction Costs*

Pacific Island Country	Cost Multiplier
Cook Islands	1.10
Federated States of Micronesia	1.30
Fiji	1.00
Kiribati	1.30
Marshall Islands	1.30
Nauru	1.30
Niue	1.30
Palau	1.30
Papua New Guinea	1.10
Samoa	1.20
Solomon Islands	1.20
Timor-Leste	1.10
Tonga	1.10
Tuvalu	1.30
Vanuatu	1.10

Note: *Estimates are based on Fiji prices and should be used with caution when used for other Pacific island countries.

[1] See iBuild, Building Solutions at https://i-build.com.au/delivery-costs-to-south-pacific-countries/
[2] BMT Quantity Surveyors. Average Building Cost in Australia. https://www.bmtqs.com.au/construction-cost-table
[3] Atlus Group. n.d. 2018 Canadian Cost Guide. http://creston.ca/DocumentCenter/View/1957/Altus-2018-Construction-Cost-Guide-web-1

4.2 Roads

The per-unit construction costs for construction of various components of sealed and unsealed roads are provided in Tables 4-3 through 4.6. These unit costs have been derived through the use of the following references:

- Road construction costs—Australia[4]
- Tuvalu asset management framework
- Nauru Asset Management Framework
- Samoa Land Transport Authority Renewal and Depreciation Funding Gap Assessment

Table 4-3: Per-Unit Building Construction Costs ($/m²)

Terrain	Flat	Rolling	Steep
Urban	$17.00	$22.00	$39.00
Rural	$22.00	$29.00	$29.00

Table 4-4: Sealed and Unsealed Roads—Per-Unit Cost for Base Pavement ($/m²)

Road Classification	Assumed Base Depth (mm)		Unit Rates ($/m²)	
	Heavy	Standard	Heavy	Standard
Arterial	450	350	$14.00	$11.00
Primary collector	350	275	$11.00	$9.00
Secondary	250	200	$8.00	$6.00
Local	200	150	$7.00	$5.00
Unsealed main	150	-	$5.00	-
Unsealed local	75	-	$3.00	-

Note: - = not available, mm = millimeter, m² = square meter.

Table 4-5: Sealed Roads—Per-Unit Cost for Surface Seal ($/m²)

Road Classification	Units of Measurement		
	Chipseal	Asphalt	Asphalt Concrete
Arterial	$10.00	$21.00	$28.00
Primary collector	$9.00	$17.00	$23.00
Secondary	$8.00	$14.00	$18.00
Local	$7.00	$14.00	$18.00

Note: m²= square meter.

The per unit costs indicated in Table 4-6 assume curb cross-section are of 0.12 m2 and footpath slab thickness of 100 millimeters (mm).

Table 4-6: Per-Unit Cost for Auxiliary Road Components

Component	Measurement Unit	Unit Cost
Curb and Gutter	$/m length	$72.00
Footpath	$/m² area	$60.00
Drainage sump with drain	$/each	$1,500.00

Note: m = meter, m² = square meter.

The per unit costs indicated in Tables 4-3 through 4-6 should be multiplied with a country specific correction factor, indicated in Table 4-2, to adjust the prices for freight and economies of scale.

[4] Australian Government. 2018. Road Construction Cost and Infrastructure Procurement Benchmarking: 2017 Update. Research Report 148. Bureau of Infrastructure, Transport and Regional Economics. Canberra.

4.3 Bridges and Culverts

Because of the significant variations in design and capacity of bridges and culverts, it is not possible to develop reasonably accurate estimates for bridge replacement or renewal based on unit costs of construction. Therefore, it is recommended to obtain records of original bridge or culvert construction cost, which can be used to determine bridge/culvert renewal or replacement cost by adjusting the original construction costs for inflation.

The unit cost for construction of road bridges and culverts provided in Table 4-7 and Table 4-8 have been derived from the recent bridge construction costs in the United States and can be used to prepare rough cost estimates for bridge/culvert replacement or component renewal. These costs are expressed in US dollars based on 2019 cost base. The unit of measurement is the surface area spanned by the bridge.

Table 4-7: Per-unit Cost for Bridge Construction

Predominant Construction Material	Steel or Steel Reinforced Concrete	Timber
Components	**$/m² of Deck Area**	**$/m² of Deck Area**
Sub-structure	$1,200	$600
Super-structure	$1,500	$800
Decking	$400	$200
Total Bridge Cost	**$3,100**	**$1,600**

Note: m^2= square meter.

Table 4-8: Per-Unit Cost for Culverts Crossings

Predominant Construction Material	Reinforced Concrete Pipe	Steel Pipe
Asset	**$/m² of Deck Area**	**$/m² of Deck Area**
Culverts	$1,000	$1,000

Note: m^2= square meter.

The per unit costs indicated in Table 4-7 and Table 4-8 should be multiplied with a country specific correction factor, indicated in Table 4-2, to adjust the prices for freight and local construction costs.

[5] U.S. Federal Highway Administration. 2019. Bridges and Structures: Bridge Replacement Unit Costs 2018. Washington, DC.

4.4 Runways and Taxiways

Greenfield construction of airport runways involves extensive planning and engineering work. Runway construction requires earthworks to create the required length of a straight pathway and may involve rock blasting; removal of trees, vegetation, and debris; and removing and stockpiling of topsoil and moving earth to create a graded surface. In countries where land is limited, it may also require reclaiming land from the ocean. Base pavement is typically constructed from durable aggregates of required depth based on traffic needs, suitably compacted. The base pavement supports the surface layer by taking the structural loading and spreading it evenly over a large area. The base pavement for a runway can vary from 500 mm to 1,200 mm, depending on the type of aircraft the runway is designed for.

Surface pavement for the runway is typically constructed from superior quality asphalt concrete or concrete, to withstand high temperatures generated during aircraft landing. Chip seal is not viable for runway surfacing. The surface pavement requires periodic renewal.

Estimates of runway replacement costs, with class 5 accuracy, can be developed based on the per-unit construction costs, shown in Table 4-9.

Table 4-9: Per-Unit Replacement Cost of Runway/Taxiway

Runway Classification	Unit Rate	Heavy Duty	Standard	Light Duty
Base preparation	$/m^2	$150.00	$90.00	$60.00
Surface seal	$/m^2	$100.00	$75.00	$60.00
Drainage sumps	$/#	$3,000.00	$2,000.00	$1,500.00
Security fences	$/m	$100.00	$70.00	$40.00

Note: the references used to develop average per unit costs includes Republic of Nauru Asset Management Plan—2019, and observation of condition assessment of the Nauru roads, runway and taxiway areas by Fulton Hogan 2016 and updated by the consultant.

= cost of drainage sump, m^2 = square meter.

The unit costs in Table 4-9 should be multiplied with a correction factor from Table 4-2 to obtain country-specific unit costs.

[6] US Army Corps Engineers. n.d. Unified Facilities Criteria UFC 4-152-01. US Department of Defense.

4.5 Wharfs and Jetties

Because of significant variation in the designs of ports and boat harbors to suit site-specific conditions for docking of ships, it is very difficult to develop reasonably accurate estimates for wharf or boat harbor replacement or renewal, with the benefit of their detailed design. In particular, the cost of support structures and piles is highly variable.[6] Estimates of wharf or jetty construction costs, with class 5 accuracy, can be developed based on the per-unit construction costs given in Table 4-10. These costs do not include the costs of dredging for approach channels, mooring systems, or stationary cranes.

The following references were used to develop average per unit costs:

- Cost Elements to Be Considered in the Design of Marine Infrastructures—Kenneth Wong—Singapore Institute of Surveyors and Valuers.

Table 4-10: Per-Unit Replacement Cost of Wharfs and Jetties

Predominant Construction Material	Steel or Steel Reinforced Concrete	Timber
Components	**$/m² of Loading Area**	**$/m² of Loading Area**
Support Structure	$1,200	$600
Decking	$400	$200
Total Wharf Cost	**$1,600**	**$800**

Note: m²= square meter.

The unit costs provided in Table 4-10 should be multiplied with a correction factor from Table 4-2 to obtain country-specific unit costs.

4.6 Coastal Protection Structures

Because of the significant variations in design and capacity of bridges and culverts, it is not possible to develop The cost of constructing coastal protection structures can vary over a broad range depending upon tidal range, ground conditions, structure shape and design, slopes, local availability, and haulage and transport of materials. Table 8-8 shows indicative costs of coastal protection structures,[7] which would need to be refined when detailed designs are prepared.

Table 4-11: Indicative Unit Costs for Coastal Protection

Coastal Protection Type	Measurement Unit	Per-unit Price in $
Steel reinforced concrete seawall	m² wall area	$4,000 to $6,000
Rock masonry wall	m² wall area	$2,500 to $3,500
Rock Revetments	m³ - volume of rock	$150 to $250
Beach nourishment	m³ - volume of sand or gravel	$10 to $25

Note: m² = square meter, m³ = cubic meter.

[7] Thomas Hudson, Kevin Keating, Angus Pettit. 2019. Cost Estimation For Coastal Protection – Summary of Evidence Report –SC080039/R7. Environmental Agency of the United Kingdom.
[8] Prices updated for inflation and currency correction in Gold Coast Water Unit Rates Review – 2008.

4.7 Water and Sewer Infrastructure

The cost of water desalination plants depends on a number of variables, including the chemistry of the in-take water, and the treatment technology. When the intake water supply has lower total dissolved solids it results in lower plant costs. For water storage, above-ground plastic storage tanks are the most economical option for home-based rain harvesting systems. Plastic water tanks for up to 10,000-gallon storage capacity can be purchased for about $10,000. Fiber-glass water storage tanks are available in sizes for up to 40,000-gallon capacity. For sizes larger than 40,000-gallon capacity, steel or concrete tanks are the only option. For water distribution under pressure, polyvinyl chloride (PVC) pipes installed through trench and cover are the most economical option. For sewage collection and treatment, the typical infrastructure includes a network of PVC pipes and sewer manholes through which sewer flows under gravity and sewage treatment plant.

Tables 4-12 and 4-13, respectively, show the unit-costs in 2019 US dollars for construction of water production and distribution and sewer collection and treatment infrastructure[8] in Fiji. The unit costs in Table 4-12 and 4-13 should be multiplied with a correction factor from Table 4-2 to obtain country specific unit costs. The indicated construction costs are based on the following reference and have been suitably updated for inflation to reflect the construction costs in 2019 US dollars in Fiji:

- Gold Coast City—Water and Sewer System Unit Rate Review (2008) by Hyder Consulting Pty Ltd.

Table 4-12: Unit Costs for Water Production and Distribution Infrastructure

Infrastructure Asset	Unit	Cost
Cost of water desalination plant	$/m^3/day	$1,000
Cost of ground level water storage tanks	300 m^3	$220,000
	500 m^3	$360,000
	1000 m^3	$470,000
	2000 m^3	$760,000
Cost of pressurized PVC water lines	$/m for 100 mm pipe	$100
	$/m for 150 mm pipe	$170
	$/m for 200 mm pipe	$230
	$/m for 250 mm pipe	$270
Cost of water manholes	Each	$10,000
Cost of pumping stations	$/kW of Capacity	$4,500

Note: kW = kilowatt, M = meter, mm = millimeter, m^3 = cubic meter, PVC = polyvinyl chloride.

Table 4-13: Unit Costs for Sewage Collection and Treatment Infrastructure

Infrastructure Asset	Unit	Cost
Sewage treatment plant	$/m^3/day	$750
Cost of pressurized PVC water lines	$/m for 150 mm pipe	$225
	$/m for 225 mm pipe	$290
	$/m for 250 mm pipe	$300
	$/m for 300 mm pipe	$380
Cost of water manholes	Each	$10,000

Note: m = meter, mm = millimeter, m^3 = cubic meter

4.8 Electricity Infrastructure

For electricity infrastructure, there are far too many line construction configurations and equipment ratings in use in different countries that impact the unit costs and they cannot be all covered in this document. Therefore, it is strongly recommended that to obtain accurate construction prices in a specific country, the electric utility in that country should be contacted by the Pacific Catastrophe Risk Assessment and Financing Initiative.

Table 4-14: Unit Costs for Electricity Infrastructure

Infrastructure Asset	Unit	Cost
11kV, 3ph, 1 circuit overhead line (120 mm^2 AAC)	$/km	$60,000
11kV, 3ph, 1 circuit overhead line (120 mm^2 AAC with ABC LV underbuilt)	$/km	$85,000
11kV, XLPE, 3ph, (120 mm^2 Copper) direct buried	$/km	$150,000
100 kVA pole mounted transformer (3 phase)	$/each	$2,000
300 kVA pad mounted transformer (3 phase)	$/each	$4,000
5 MW medium speed diesel generator	$/each	$5,550,000
1 MW high speed diesel generator	$/each	$160,000
100 kW PV solar power	$/each	$200,000

Note: ACC= all aluminum conductor, ABC LV = aerial bundle conductor low voltage, kV = kilovolt, ph = phase, PV = Photovoltaics.
Source: Nauru Utilities Corporation.

The unit costs indicated in Table 4-14 are indicative costs for some typical line configurations and equipment ratings and these costs represent the 2019 construction costs in Fiji. The costs in Table 4-14 represent the construction costs in 2019 US dollars in Fiji and should be multiplied with the correction factors indicated in Table 4-2 to obtain the country-specific construction costs.

4.9 Telecommunication Infrastructure

For telecommunication infrastructure, there are far too many line construction configurations and equipment ratings in use in different countries that impact the unit costs, and they cannot be all covered in this document. Therefore, it is strongly recommended that to obtain accurate construction prices in a specific country, the telecom utility in that country should be contacted by the Pacific Catastrophe Risk Assessment and Financing Initiative.

5. Buildings—Condition Assessment

5.1. Main Components

Table 5-1 lists the main components and subcomponents of buildings, their commonly used types and construction materials, as well as typical useful life of building components in the environment encountered in Pacific countries. It is noteworthy that, depending on the quality of building design, construction, and maintenance, the actual useful life of building components may deviate significantly from the typical useful life indicated in Table 5-1.

Subject to renewal of the short-life components on a timely basis,Table 5-2 shows indicative typical life for overall building assets. The typical useful life for a building is determined by the typical useful life of materials employed in construction of the superstructure.

Building substructure consists of foundation pillars and foundation walls and/or concrete slabs, all intended to provide a stable base for load bearing of the superstructure members. The superstructure supports the weight of the dead and live structural loads related to floors and roof and creates the living space. It consists of self-supporting walls, posts and beams, floor joists, and roof trusses. When concrete slab is used for the foundation, it also serves as the subfloor to support floor loads.

The building envelope includes the roof coverings and wall cladding. The building envelope provides protection to all other components of the building from weather elements, including moisture, wind, and extreme temperature. Since the building envelope members are exposed to weather elements, they must be manufactured out of materials that resist degradation when exposed to weather elements. Building roofs play two distinct roles: they provide a water-tight envelope on top of the building to protect the interior space from rain and sun and they are used to harvest rainwater for water supply. Windows allow entry of natural light and openable windows also permit ventilation. No exterior wall cladding is required when the exterior walls are made of reinforced concrete or masonry. But in the case of wood or steel framing structures, external wall cladding in the form of aluminum, galvanised iron, engineered wood, or fiber reinforced cement siding is commonly used.

The interior finishes consist of ceilings, partition walls, and floor finishes. Partition walls separate living spaces into different rooms and interior finishes provide visually appealing paintable surfaces to provide aesthetically pleasing, easily cleanable functional living space. Ceramic or linoleum tiles are commonly used for floor finishes, although some buildings with concrete slab as subfloor, do not employ any floor finishes.

The services serve sanitation, ventilation, air conditioning, lighting, and comfort needs.

Ventilating fans and air conditioning are used to control interior building temperature to improve comfort. Plumbing provides pressurized water supply in buildings and drains to remove residue from sinks, bathtubs, and toilets into the sewer/septic holding tanks. Electrical wiring facilitates lighting and power plugs throughout the building. The site access provides safe and secure access to the buildings.

Table 5-1: Building Components and Their Typical Useful Life

Main Component	Sub Component	Sub-Component Type	Typical Useful Life
1. Sub Structure	Subsurface (foundation) pillars/posts	Concrete pillars	80 years
		Steel pillars	80 years
	Subsurface (foundation) walls	Foundation wall	80 years
	Partially subsurface (foundation) slabs	Poured slab	80 years
2. Super Structure	Columns	Timber	60 years
		Steel	80 years
		Steel reinforced concrete	80 years
	Walls	Timber	60 years
		Steel	80 years
		Masonry	80 years
		Steel reinforced concrete	80 years
	Roof	Timber roof truss	60 years
		Steel roof truss	80 years
		Steel reinforced concrete slab	80 years
	Sub-floor	Timber joists	60 years
		Steel joists	80 years
		Concrete	80 years
3. Building Envelope (External Finishes)	Roof finishes	Asbestos	30 years
		Concrete	60 years
		Galvanized iron sheeting	20 years
		Superior metal painted sheet	30 years
		Tiles	30 years
		Asphalt shingles	20 years
	Wall cladding	Concrete walls	60 years
		Masonry	60 years
		Fibrous cement board	30 years
		Galvanized iron sheeting	20 years
		Painted steel or aluminum siding	30 years
		Vinyl siding	30 years
		Timber siding	20 years
		Hardy plank	30 years
	Balconies / veranda/decking	Timber	20 years
		Concrete	60 years
		Engineered wood	30 years
	Doors and windows	Doors and windows	30 years
	Soffits/fascia	Windows	30 years
	Rain water gutters/down pipes	Rain water gutters/down pipes	30 years

Table 5-1: Building Components and Their Typical Useful Life (continued)

Main Component	Sub Component	Sub-Component Type	Typical Useful Life
4. Interior finishes (fitouts)	Interior wall or ceiling finishes	Fibrous cement	60 years
		Hardboard/timber	60 years
		Plasterboard/gyprock	60 years
		Concrete	60 years
	Floor finishes	Carpet	20 years
		Ceramic or porcelain tiles	30 years
		Timber	20 years
		Vinyl	20 years
		Engineered wood	20 years
		Epoxy coating on concrete	20 years
5. Services	Mechanical	Ducted air-conditioning	20 years
		Evaporative cooler	20 years
		Split System air conditioners	20 years
		Wall air conditioners	20 years
		Ceiling fans	20 years
	Plumbing	Above grade water tanks	30 years
		Below grade water tanks	60 years
		Plumbing fixtures	30 years
		Sewage pipes	30 years
		Septic tanks	30 years
	Electrical	Transformers	30 years
		Service panels	30 years
		Light and power wiring	30 years
		Communications/security	30 years
		Solar panel & controls	20 years
	Fire protection	Sprinkler system	30 years
		Fire alarms	30 years
	Conveyance	Elevators/escalators	30 years

Table 5-2: Typical Useful Life of Buildings (as whole asset)

Infrastructure Asset	Typical Useful life
Buildings with superstructure constructed predominantly from timber	60 years
Buildings with superstructure constructed predominantly from steel or concrete	80 years

5.2.Typical Degradation Modes

The strength of most construction materials and adhesives decreases with age, mainly due to oxidation. Typical degradation mode for concrete building structures involves concrete spalling and corrosion of steel rebar, both of which result in reduced structural strength. Degradation in buildings close to the coastline accelerates due to salt spray from the ocean carried by wind. Similarly, if sand from the ocean or ocean water is used to mix sand during construction, the presence of sea salt in the sand significantly reduces the useful life of structures. The structure is considered to have reached the end of its service life when the reduced strength lowers the safety factor for the structure to less than acceptable level.

Wood framing walls get weakened in structural strength due to wood rot if wood is repeatedly exposed to moisture. Any cracks in wall cladding or roof leaks can expose structural timber to moisture, causing asset impairment. Wood framing can also be weakened by insects that can bore through wood, e.g., termites.

Corrugated iron roofs are particularly subject to corrosion, which can severely reduce their service life when a building is close to the ocean. If a roof develops a leak all other components including structure, walls, flooring, and electrical wiring can be impaired. Continued dampness from water leaks may result in mold growth on interior components of buildings, which poses a serious health hazard to occupants. All components with steel members, such as door and window hinges and louver hardware and air conditioner frames experience corrosion under ocean spray, which affects their normal functions. Ceramic tile floors can experience premature degradation, resulting in detachment of the tiles from the subfloor when installed using inappropriate cement for grout. Similarly, linoleum floor tiles detach from the subfloor when exposed to moisture.

PVC water pipes may develop leaks due to incorrect use of pumping motors with excessive pressure. Joints in plumbing pipes may fail if they are accidentally subjected to excessive pressure due to fault pumps. The service life of electrical wiring, when properly designed and protected against overcurrent and over-voltage, should outlast the building structure. However, if the overcurrent protection becomes dysfunctional, electrical wiring can fail prematurely.

All building components, including structures, may fail or be impaired, resulting in loss of service life during a cyclonic storm or storm surge. Building roofs, structural walls, or columns may fail from excessive force exerted by cyclonic wind or water surge and the building foundations can be structurally damaged during shifting of the soil below the foundations. Table 5-3 shows the levels of vulnerability of buildings to typical natural disasters.

Table 5-3: Vulnerability of Buildings to Common Natural Disasters

Natural Disaster	Vulnerability to Damage	Asset Components Most at Risk
Earthquake	High	Substructure, superstructure
Flooding	High	Substructure, building envelope, interior finishes
Windstorm	High	Building envelope, superstructure

5.3. Physical Condition Assessment Techniques

The condition assessment of the buildings involves assessment of (i) structural and (ii) nonstructural components, as described below and ranking the condition of all assets on a scale of 1 to 5, based on the criteria summarized in Table 2-1 (section 2):

i. Condition assessment of structural components

After successful inspection of the structural components during warranty, structural inspections are not required until after the building structure has passed half of its normal economic life. After this stage, structural assessments should be performed once every 10 years. Condition assessment of the structure is also necessary immediately after a major natural disaster event that may have affected the building structure. The condition assessment of structural members must be performed by a competent person.

The structural assessment is performed in two phases: preliminary inspections and detailed assessment. Because the detailed structural assessments are quite costly, preliminary inspections are carried out first and the detailed assessments are performed only if warranted, based on the findings of the preliminary inspections.

The preliminary inspections, usually carried out by a competent building inspector, involve the following tasks:

- a review of the original design drawings and construction records to identify specified structural loads and compare them to the actual loads to confirm adequacy of the structural members;
- site inspections and review of maintenance and repair records to identify if any alterations or additions have been made after the original construction and determine the adverse impacts on such additions and alterations on structural integrity of the building;
- maintenance staff interviews to identity known areas of distress, corrosion, cracking, or water leakage;
- building survey and visual inspection to document structural defects, signs of damage, distress, deformation, or deterioration;
- site assessment using nondestructive techniques to confirm adequacy of structural systems; and
- preliminary numerical analysis to verify the adequacy of critical elements, using approximate methods, focused on suspect areas or building elements.

The preliminary inspections would either identify the need for immediate corrective action or provide satisfactory results indicating that the structure was adequate. When preliminary inspections identify serious structural concerns, possible recommendations may include installation of temporary shoring or bracing to prevent structural collapse, restriction of access to building, or installation of a protective enclosure to minimize infiltration of weather elements. In some cases, the results of preliminary investigations may be inconclusive in identifying the need for detailed structural assessment.

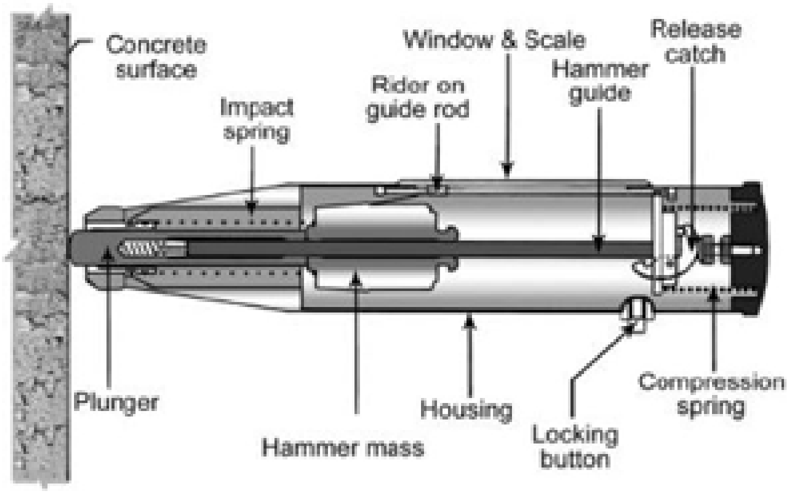
The detailed structural assessment should be performed by a competent structural engineer, involve investigations and extensive engineering work, and typically consists of the following tasks:

- Document search—including the search for original design drawings and as-built construction records from the company that designed or constructed the building, including interviews with the structural engineer who designed the building or managed its construction.
- Building examination carried out systematically and scientifically to determine structural concerns, including structural defects, damage, deformation, or deterioration of structural members.
- Testing of materials used in construction to quantify structural capacities and/or quantification of the reduction in strength due to deterioration or defects; e.g., when the crossection area of a structural member is reduced due to corrosion, its reduced strength should be calculated and compared with the design loads.

- Structural analysis to confirm structural adequacy of a component or portion of the building or the entire building.

When visual inspection reveal defects, several non-destructive tests are available to determine the extent of degradation, including (i) measurement of concrete surface hardness through rebound hammer test, as shown in Figure 5.1, and (ii) performing compressive and tensile strength testing on core samples.[9]

Figure 5-1: Condition Assessment of Concrete Structures



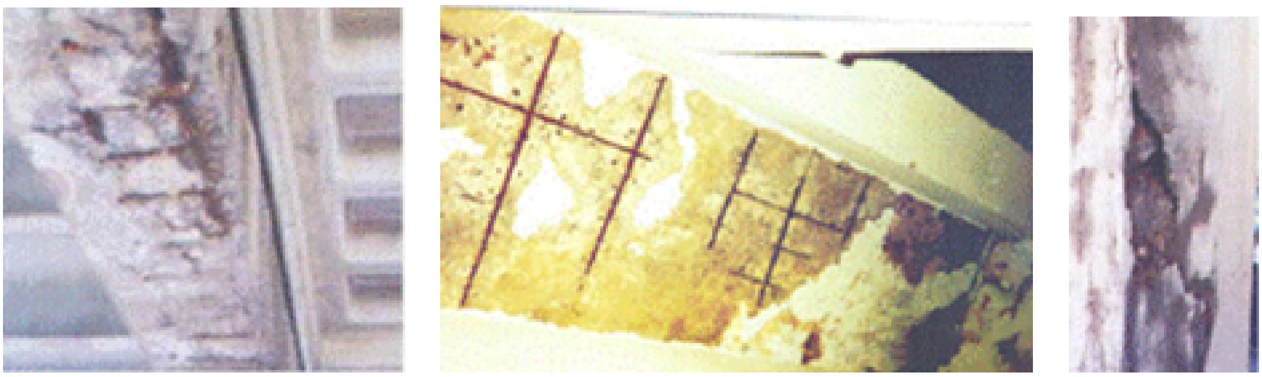
ii. Condition assessment of nonstructural components

Condition assessment of all building components other than the structure can be performed by a competent building inspector. Condition assessment of the non-structural building components can be performed through visual inspection and carefully looking at the symptoms and identifying root causes of degradation.

For example, damaged ceilings, walls, and floors can be identified through visual inspection, but the root cause of such damage may be exposure to water from condensation, plumbing pipe leaks, or leaks in roof or exterior walls. Degradation of windows and doors may be indicated by deformation of frame and sashes, rusty frames and hardware, or broken or cracked glass. Faulty plumbing may have leaky joints in pressurized water pipes or drains. Compressors in air conditioning systems may fail due to excessive corrosion of the moving parts. Electrical systems may display arching due to loose connections.

The following photographs illustrate building components in poor or very poor condition:

Figure 5-2: Degradation of Building Concrete Structures



[9] The Constructor. Civil Engineering Home. https://theconstructor.org/concrete/rebound-hammer-test-concrete-ndt/2837/

Figure 5-2 shows building concrete structures with serious deficiencies, such as structural cracks in concrete beams, columns, walls and slabs, deformation of vertical structural members, and exposed steel rebar. Such structures should be rated as "very poor". Similarly, when masonry walls develop structural cracks, due to uneven settling of the soil below foundation walls, as shown in Figure 5-3. Walls like this should be ranked "very poor".

Figure 5-3: Structural Cracks in Masonry

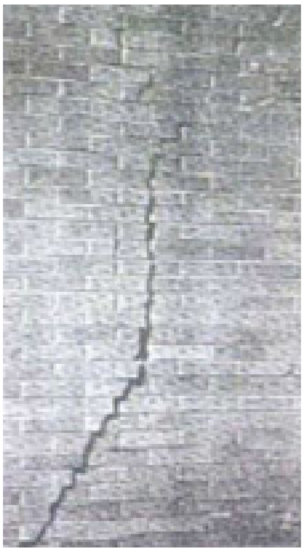


Figure 5-4 shows the vinyl tiles lifting off an office floor—this flooring should be ranked as very poor.

Figure 5-4: Structural Cracks in Masonry

iii. Functional performance of buildings

In assessing the functional performance of a building, the following factors should be considered:

- safety and security of occupants—major structural defects, fire hazards;
- potential health risks—water leaks, presence of mold;
- adequacy and suitability of available space and services; and
- operating expenditure—annual costs related to building repairs.

Table 5-4 summarizes the common degradation modes and distress symptoms that should be considered when assigning physical condition ratings to building components. When the field inspectors are unsure of how to rank the condition of some components, the details of component degradation should be recorded and photographed for referral to a structural engineer/architect.

Table 5-4: Building Components Typical Degradation Modes and Condition Assessment Considerations

Main Component	Component Type	Degradation Modes	Distress Symptoms to Consider When Selecting Condition Rating
1. Substructure	Concrete pillars	Cracks, spalling, rebar corrosion, deflection	Number of and severity of structural cracks, depth and surface area of concrete affected by spalling, extent of rebar corrosion, degree of column deflection from vertical
	Steel pillars	Corrosion, deflection, deformation	Severity of corrosion, reduction in effective cross-section area due to corrosion, degree of deflection from vertical
	Concrete foundation wall	Cracks, spalling, rebar corrosion, deflection, deformation	Number of and severity of structural cracks, depth and surface area affected by spalling, extent of rebar corrosion, degree of deflection from vertical
	Concrete poured slab	Cracks, spalling, rebar corrosion, deformation	Number of and severity of structural cracks, depth and surface area affected by spalling, extent of rebar corrosion, extent of deformation
2. Superstructure	Timber structural member	Wood decay, termite damage, cracks, deflection	Extent of damage from decay or termites, number of and severity of cracks, reduction in effective cross-section area and strength, degree of deflection from vertical
	Steel structural member	Corrosion, deflection, deformation	Severity of corrosion, reduction in cross-section area due to corrosion, degree of deflection from vertical
	Concrete structural member	Cracks, spalling, rebar corrosion, deflection, deformation	Number of and severity of structural cracks, depth and surface area affected by spalling, extent of rebar corrosion, degree of deflection from vertical
	Masonry walls or pillars	Cracks, surface delamination, missing bricks, deflection,deformation	Number of and severity of structural cracks, Surface area affected by surface delamination or missing bricks, degree of exposure to weather elements, degree of deflection from vertical

Table 5-4: Building Components Typical Degradation Modes and Condition Assessment Considerations (continued)

Main Component	Sub Component	Sub-Component Type	Typical Useful Life
3. Building Envelope	Timber siding	Wood decay, warped panels, missing panels	Extent of damage from decay , extent of area over which panels are warped or missing exposing the building interior to risk of water ingress
	Vinyl or synthetic material siding	Surface degradation, warped or missing panels	Extent of area over which panels are degraded, warped or missing exposing the building interior to risk of water ingress
	Metal siding	Peeling of paint, corrosion (rusting), warped or missing panels	Extent of area over which panels are degraded, warped or missing exposing the building interior to risk of water ingress
	Stucco	Cracks, swelling, flaking, efflorescence	Extent of wall area over which stucco has degraded due to cracks, swelling, flaking, efflorescence exposing the building interior to risk of water ingress
	Roof - galvanized iron sheeting	Corrosion	Degree of corrosion and roof area affected, the risk of water ingress into building interior
	Superior metal painted sheet	Discoloration, paint flaking, corrosion	Extent of roof area affected, the risk of water ingress into building interior
	Roof tiles	Cracked, damaged or missing tiles	Extent of roof area affected, the risk of water ingress into building interior
	Asphalt shingles	Warped (curled) or missing shingles	Extent of roof area affected, the risk of water ingress into building interior
	Doors and windows	broken, cracked glass, warped frames, decayed wood	Extent of degradation and number of defective doors and windows
4. Interior Finishes (fitouts)	Timber	Wood decay, warped panels, missing panels, mould/fungi growth	Extent of damage from decay, extent of area over which panels are warped or missing, extent of wall/ceiling area infested with mould
	Plaster	Cracks, holes, warped, bubbling, discolouration, mould/fungi growth	Extent of area with defective plaster, extent of wall/ceiling area infested with mould
	Ceramic or porcelain tiles	Cracked, delaminated, missing tiles	Extent of area with defective/missing tiles
	Vinyl	Delaminated or missing tiles, mould/fungi growth	Extent of area with defective vinyl floor
	Carpet	Worn out, stained, torn or burnt	Extent of area with defective carpet
5. Services	Air conditioning, fans	Defective equipment	Extent and severity of defects
	Plumbing	Cracked plumbing fixtures, leaking pipes	Extent and severity of defects
	Electrical	Frayed insulation, loose connections, overheating	Extent and severity of defects
	Water/sewer	leaking or blocked pipes	Extent and severity of defects

5.4. Recommendations for Maintenance

The maintenance plan for a building should be tailored to its specific design and construction. The maintenance plan should therefore be developed at the same time as a new building is being designed and constructed. It is important to keep a complete set of "as-built" drawings for the building and any changes made during major maintenance should be recorded on the drawings.

The maintenance requirements for buildings include four specific types of activities, as described below:

i. Scheduled inspections and minor maintenance

Scheduled inspections and minor maintenance at regularly scheduled intervals are required to perform minor repairs and/or replacement of degraded parts identified through inspections, to avoid more serious damage and asset impairment. The minor maintenance activities are covered through operation and management budgets and include the following tasks:

a. Grade inspection around the building foundation to confirm water is draining away from the foundations and raising the topsoil level near foundations, where required.
b. Inspect foundations to identify structural cracks or concrete spalling.
c. Inspect masonry walls to identify cracks or damage to walls.
d. Inspect exterior walls and roof to identify all sources of water leaks into the building interior and performing emergency repairs where required to prevent water ingress into the building.
e. Inspect eves and gutters to ensure they are not detached from the building or blocked by leaves or other debris. Make repairs where required.
f. Inspect floors and interior walls to identify any damage, which would affect functionality of buildings. Make emergency repairs where required.
g. Inspect doors and windows to identify warped frames or broken glass and make repairs when required.
h. Inspect plumbing system to identify damaged plumbing fixtures, blocked or leaking drains, damaged pipes, or defective pumps. Repair as required.
i. Inspect electrical systems, including light fixtures. Repair as required.
j. Inspect ceiling fans and air conditioners, identify extent of rust, inspect for proper operation. Repair as required.

ii. Planned condition assessment

Building condition assessment is generally performed once every 5 years or after a major cyclone. It involves comprehensive assessment of all building components to determine the physical condition of building components and assess their operating performance and remaining useful life. The condition assessment is undertaken to reveal the need for major repairs or refurbishment or replacement of components during the next 5-year period. (i.e., determining the need for roof replacement).

iii. Reactive maintenance

Reactive maintenance for buildings involves repairing specific building components when they fail, to maintain building functionality and service levels and to prevent further impairment, i.e., replacing an air conditioner compressor after it has failed. Reactive maintenance could be triggered based on the findings of annual inspection or planned condition assessment or any serious asset impairment reported by the asset users. The reactive maintenance is generally covered through O&M budgets, but may occasionally involve capital expenditure, depending on the scope of required repairs.

iv. Planned major repairs and refurbishment

These maintenance activities are performed in response to the repair/refurbishment needs identified through planned condition assessment, i.e., replacement of roof, when it is determined to have reached the end of its life. These are generally covered through capital budgets. When repairs or refurbishment of an asset is not considered economically efficient, the asset is retired from service and replaced.

5.5.Data Collection Requirements

The data collection requirements for the asset management functions of buildings are summarized in Table 5-5.

Table 5-5: Building Data Collection Requirements

Asset Hierarchy	Asset ID
	Name of country
	Service sector
	Asset category
	Asset location - street address
	Asset location - GPS coordinates
Construction Details	Soil type
	Ground slope
	Construction class (basic, standard or superior)
	Floor area
	Number of stories
	Foundation bracing
	Roof shape
	Roof pitch
	Shutter type
	Minimum floor height
	Maximum floor height
	Plan shape
	Tower presence
	Balcony presence
	Wall opening
Asset Component Type	Substructure type
	Superstructure type, including type of columns, walls, roof truss and floor joists
	External finishes for roof, wall cladding, doors, windows, veranda/decks, soffit, facia and eaves troughs
	Interior finishes, including walls, ceiling, floor finishes
	Services, including mechanical, plumbing, electrical , fire protection and conveyance services

Table 5-5: Building Data Collection Requirements (continued)

Asset Component Condition	Condition of substructure
	Basis for condition rating, if the rating is less than 3
	Condition of superstructure
	Basis for condition rating, if the rating is less than 3
	Condition of building envelope
	Basis for condition rating, if the rating is less than 3
	Condition of interior finishes
	Basis for condition rating, if the rating is less than 3
	Condition of services
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Year of occupancy
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Unit cost for substructure construction
	Unit cost for superstructure construction
	Unit cost for building envelope renewal
	Unit cost for service renewal

6. Roads—Condition Assessment

6.1. Main Components

Sealed roads consist of the following components:

- seal (surface layer)
- pavement base course
- formation (earthwork grading)
- curb and gutter
- drainage sumps
- footpaths

While the first three components on the list are essential, the last three—curb and gutter, drainage sumps, and footpaths—are provided on some roads to improve functionality and to retard degradation of road surface due to flooding and soil erosion. Related components essential for safe road operation include traffic lights, sign boards, and so on.

A sealed road surface—chip seal, asphalt, or asphalt concrete—safely provides a smooth, sealed surface to facilitate traffic flow at required speeds. The paved road surface also prevents ponding of road surfaces, by draining water into gutters along the curbside, and prevents degradation of the base. Concrete curbs provide structural support to paving and help extend its service life. Absent concrete curbs, the pavement will erode at the edges and degrade quickly, compromising the width of travel lanes. The road surface layer also has the road markings, which help drivers stay within lanes, reducing risk of collision. For safe driving, lane markings should be visible.

The base course provides structural support to the surface layer and commonly consists of aggregate (gravel) of required thickness installed on top of graded earthwork and compacted in layers. The road formation component represents the earthwork below the base course to meet the grading needs.

The unsealed roads have only two main components:

- surface layer pavement - (graded aggregate surface)
- formation - (earthwork under the pavement)

The compacted pavement provides structural support to maintain deflection at acceptable levels when subjected to vehicle weight. The pavement is generally graded with a blade to maintain a smooth surface, with the crest maintained at the center of the pavement and sloping to the sides to allow drainage of water to the sides. The road formation represents the earthwork below the unsealed pavement to meet grading needs.

The typical life of road components can vary broadly, by quality of surface and pavement, traffic volume, effectiveness of drainage, and quality and scope of preventative maintenance. For example, if clogged drains are not promptly repaired and water stands on the road, it accelerates surface degradation. Similarly, if the defects in road surface are not promptly repaired, it leads to larger potholes, causing the degradation of the base pavement. And if the pavement is not promptly repaired, it may erode soil in heavy rain, impairing the formation.

Road surface renewal for asphalt or asphalt concrete typically involves milling of the overlay to remove corrugations, with a fine-profile milling machine and resurfacing of the top layer. Because only the top part of the surface layer is milled and resurfaced, the lower level of asphalt (layer beneath the milled depth) is considered the long-life component and the milled depth is considered the short-life component. The short useful life of the surface is the average time between the surface renewal treatments, e.g., mill and replace for asphalt concrete reseal for chip. The long useful life for the surface is the time between complete road reconstruction, estimated to be about five times the renewal cycle.

Chip seal for road surface is designed to seal and protect pavement from oxidation and weathering by sealing the small cracks in a pavement surface and preventing the intrusion of water and air. A chip seal can also be used to address raveling (loss of aggregate), correct bleeding and flushing problems, improve skid resistance, and generally extend the pavement life. Chip seals are not suited for all pavements; the existing structure should be sound, with only minor surface defects. They are not appropriate for rutted, potholed, or severely distressed surfaces. Before application of the chip seal, all such defects must be repaired.

Several different types of binders are commonly used in a chip seal—some suitable for cold application and others for hot application. Cold applied binders include modified and unmodified medium and rapid-setting emulsions; hot applied binders include polymer-modified asphalt cements, asphalt rubber, and polymer/crumb rubber blends, as well as unmodified asphalt cements. The appropriate binder in each case is selected based on pavement condition, climate, aggregate properties, desired service life, and cost considerations. Chip seals can be applied as single chip seals or double chip seals.

If the road seal is not renewed on time and the pavement base below the surface is damaged, the typical base renewal process is to rip and remake the top 150–200 mm depth of the base pavement. During re-pavement of the base, the sub-base (layer beneath the ripped depth) is considered the long-life component, as this layer of the base is not replaced, during renewal of the pavement base; the upper layer (which is ripped and removed) is considered the short-life component. The short useful life for the base is the average time between renewal treatments, e.g., a rip and remake or granular overlay; the long useful life is the time between complete road reconstruction, estimated to be twice the base renewal cycle.

The earth formation in both sealed and unsealed roads is assumed to not degrade, with no investment requirements for renewal or replacement. The curbs, footpaths, and drainage system are replaced as a whole component when they reach the end of their lives and they do not have short-life components. Based on the above listed assumptions, typical useful life for the sealed road components are indicated in Table 6-1.

In Table 6-1, for road surface and road pavement components, a short-life and a long-life is shown. This is because when the road surface reaches the end of its life, before application of a new seal, the existing road seal material is removed through a milling operation. But during the milling operation, 100% of the original seal is not removed, but only the top portion of the seal is removed, and the lower portion remains in service. Similarly, when the base pavement reaches the end of its service life, only a fraction of the original pavement is ripped up and removed, and the lower portion of the base pavement remains in service.

Table 6-1: Sealed Road Components and their Typical Useful Life

Main Component	Component Type	Component Subtype	Component Make up		Typical Useful Life	
			Long Life (%)	Short Life (%)	Long Life	Short Life
1. Formation	Flat	n.a	n.a	100%	n.a	Indefinite
	Rolling	n.a	n.a	100%	n.a	Indefinite
	Hilly	n.a	n.a	100%	n.a	Indefinite
2. Base Pavement	Local	n.a	20%	80%	120 years	60 years
	Secondary collector	n.a	30%	70%	100 years	50 years
	Primary collector	n.a	30%	70%	90 years	45 years
	Arterial or highways	n.a	40%	60%	80 years	40 years

Table 6-1: Sealed Road Components and their Typical Useful Life (continued)

Main Component	Component Type	Component Subtype	Component Make up		Typical Useful Life	
			Long Life (%)	Short Life (%)	Long Life	Short Life
3. Surface	Local	Asphalt or asphalt concrete	10%	90%	50 years	12 years
	Secondary collector	Asphalt or asphalt concrete	10%	90%	65 years	14 years
	Primary collector	Asphalt or asphalt concrete	10%	90%	90 years	18 years
	Arterial or highways	Asphalt or asphalt concrete	10%	90%	100 years	25 years
	Local	Chipseal	40%	60%	40 years	8 years
	Secondary Collector	Chipseal	40%	60%	50 years	10 years
	Primary Collector	Chipseal	40%	60%	65 years	13 years
	Arterial or highways	Chipseal	40%	60%	80 years	16 years
4. Curb & Gutter	n.a	n.a	n.a	100%	n.a	50 years
5. Drainage Sumps	n.a	n.a	n.a	100%	n.a	50 years
6. Footpath	n.a	n.a	n.a	100%	n.a	50 years

Note: n.a = not applicable.

For unsealed roads, the short life is based on regrading of the existing gravel pavement and long life is based on replenishment of the gravel pavement through addition of fresh gravel and regrading. The earth formation for both sealed and unsealed roads is assumed not to degrade, with no investment requirements for renewal or replacement. Based on the above listed assumptions, typical useful life for the unsealed road components are indicated in Table 6-2.

Table 6-2: Unsealed Road Components and their Typical Useful Life

Main Component	Component Type	Component Subtype	Component Make up		Typical Useful Life	
			Long Life (%)	Short Life (%)	Long Life	Short Life
1. Formation	Flat		n.a	100%	n.a	Indefinite
	Rolling		n.a	100%	n.a	Indefinite
	Hilly		n.a	100%	n.a	Indefinite
2. Base Pavement	Local		50%	50%	20 years	10 years
	Secondary collector		50%	50%	10 years	5 years

As long as the surface seal is renewed in a timely manner, roads in Pacific countries are expected to provide the typical useful life indicated in Table 6-3, before requiring replacement of the base pavement.

Table 6-3: Typical Useful Life of Roads (as whole asset)

Asset	Typical Useful life
Sealed roads - local use	60 years
Sealed roads - secondary collector	50 years
Sealed roads - primary collector	45 years
Sealed roads - highways	40 years
Unsealed roads	20 years

6.2.Typical Degradation Modes

The typical degradation mode for asphalt pavement is the oxidation of binding material, which gradually decreases the pavement strength. With age, the pavement becomes brittle and starts to develop surface cracks (Figure 6-1).

Figure 6-1: Road Degradation Modes—Surface Cracks

Water seeps underneath the surface pavement through these cracks, accelerating asphalt aging. The asphalt surface eventually starts crumbling and breaking up, forming potholes in the road (Figure 6-2). Hot climates increase the oxidation rate in asphalt and over time, the pavement becomes brittle more swiftly than it would if the asphalt was in a temperate climate. Traffic volume and weight of motor vehicles also plays a role in degradation of road surfaces. High traffic volume with heavier trucks degrades the road surfaces faster. Ocean spray and frequent flooding of road surfaces with salt water accelerates degradation of the paved surfaces.

Figure 6-2: Degradation Modes of Roads—Surface Degradation Due to Ponding

The degradation and failure modes of chip seal surface roads include premature binder rise, flushing, chip loss, chip rollover, and pavement structural failures.[10] Binder rise is a natural action which occurs over the life of a chip seal and can cause flushing and bleeding. Premature binder rise or flushing can be caused by higher than expected traffic volumes or when the binder application is too high for the traffic volume. Binder rise may also lead to bleeding (Figure 6-3), significantly reducing surface skid resistance.

Figure 6-3: Degradation Modes of Chip Seal Roads—Bleeding and Tracking

Timely resealing of asphalt pavement prevents moisture from penetrating its surface and substantially slows oxidation of the underlying pavement. If cracks in the road surface are resealed in a timely manner, it helps extend the service life of paving, but when the cracks are not resealed, the paved surfaces degrade more quickly.

Painted road markings begin to wear and fade with time.

Concrete curbs also degrade in strength with time, but concrete degrades more slowly than asphalt. However, if the soil below the concrete curb washes away, absent steel reinforcing, the concrete curb breaks up. Once the curb has been damaged, it exposes the asphalt surface to water seepage from the edges, and road edges begin to crumble and break up. Therefore, to protect road pavement, it is important to repair the concrete curbs promptly.

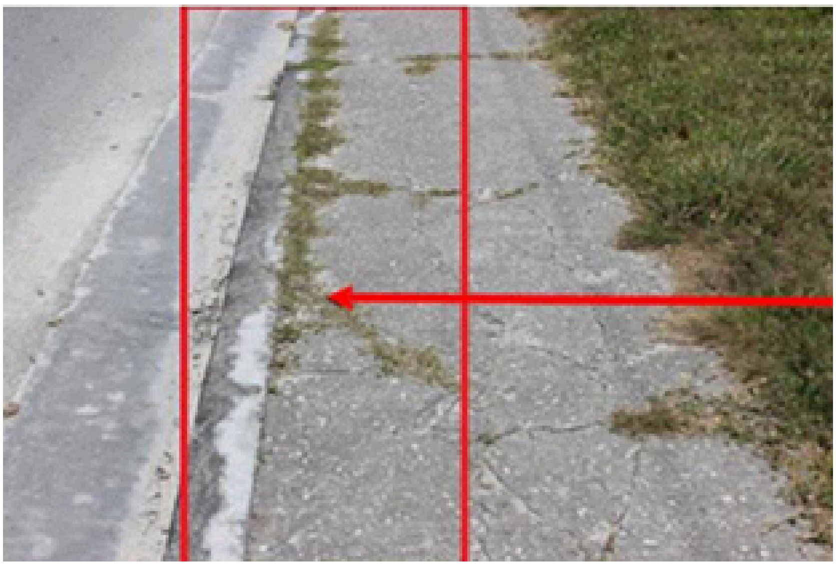
Figure 6-4: Degradation Modes—Clogged Drainage Sump

Road degradation accelerates when the drainage system fails to function, resulting in ponding of the road surfaces over extended durations (Figure 6-4). Lids of the sumps can get damaged under heavy vehicle loading, allowing debris to get into these sumps and causing blockage. When pipes connecting the sumps to soak pits are clogged or the soak pits are saturated road drainage systems fail. When the pipes connecting the sumps to soak pits are clogged, or the soak pits are saturated, they result in failure of the road drainage system, as shown in Figure 6-4.

[10] New Zealand Transport Agency. 2011. Chip Seal Failure and Repairs. Chapter 12 https://www.nzta.govt.nz/assets/resources/chipsealing-new-zealand-manual/docs/12-chipseal-failures-and-repairs.pdf

Concrete footpaths degrade due to soil erosion if the soil below the footpath is washed away during a rainstorm. Grass and weed roots can start growing through the footpath, causing cracking of the concrete footpath (Figure 6-5).

Figure 6-5: Degradation Modes of Concrete Footpath



Typical degradation mode for unsealed roads include deformation (sinking) of the pavement under vehicle loads, erosion of the pavement and soil during flooding, as shown in Figure 6-6.

Figure 6-6: Degradation Modes—Unsealed Roads

Road sections may also fail or experience impairment, reducing service life during a flooding event. During earthquakes, sections of the underlying earth may develop cracks, rendering the roads impassable.
Table 6-4 shows the level of vulnerability of roads to typical natural disasters.

Table 6-4: Vulnerability of Roads to Natural Disasters

Natural Disaster	Vulnerability to Damage	Asset Components Most at Risk
Earthquake	Low in plains, high in mountains	Formation
Flooding	High	Formation, base pavement, surface seal
Windstorm	Low	Traffic lights, signboards

6.3.Physical Condition Assessment Techniques

Condition assessment of roads and their components should be performed by a civil engineer or competent road inspector. Condition assessment of the roads and their components can be performed through visual inspection by carefully examining the condition of the pavement surfaces, concrete curbs, and drainage system and considering the number of potholes per kilometer length of the road and their condition.

In countries with extensive road networks, it is more appropriate to employ a tiered approach for condition assessment of the road network, in which tier 1 assessments typically include collection of data and road surface evaluation through non-invasive vehicle mounted equipment, shown in Figure 6-7, to collection data related to the following parameters:

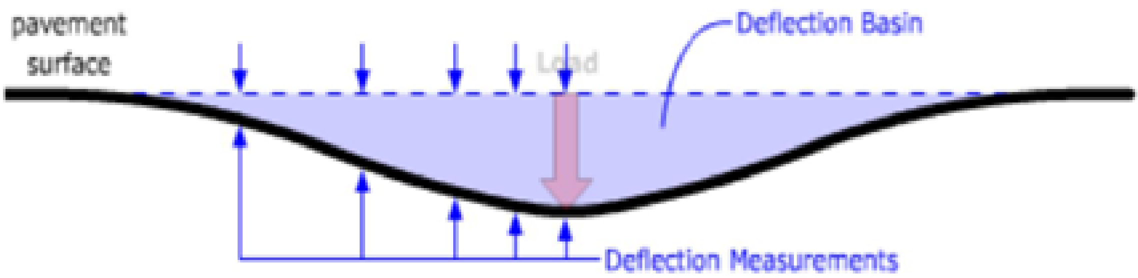
- pavement roughness or ride quality assessment
- surface distress
- rutting
- skid resistance

Figure 6-7: Road Evaluation Data Collection through Vehicle Mounted Devices

In road roughness assessment, pavement surface irregularities affecting user comfort and safety are assessed, the information collected through the rider's perception of ride quality. Surface distress is a measure of the extent of surface cracking, patching, or rutting; this information is commonly collected through continuous windshield surveys or videos. Skid resistance is measured in accordance with ASTM Standard E274 using a lock wheel skid trailer.

More detailed assessments can be performed during Tier 2 assessments performed only on road sections found in poor condition during Tier 1 inspections. Tier 2 assessments may include assessment of load carrying capacity through lab tests performed on bore/core samples or nondestructive testing, such as deflection measurements through falling weight deflectometer or ground penetrating radar assessments.

Figure 6-8: Pavement Deflection Assessments Under Load



If the surface seal is maintained in satisfactory condition, the base course condition should not be a concern, but, in severe flooding, the base course layer may get washed away. The condition assessment of the base course, curbs, gutters and drainage sumps, and footpaths is assessed through visual inspection.

The condition assessment of unsealed roads is commonly performed through visual inspection and expressed through the degree of degradation of surface and base layer. Figure 6-9 shows roads in poor and very poor condition. The road on the left has extensive damage to the surface layer but the base layer appears to be unharmed. The road on the right would require extensive repairs to base layer before it can be sealed and therefore it is ranked in worse condition.

Figure 6-9: Pavement Deflection Assessments Under Load

(a) poor condition

(b) very poor condition

Table 6-5 summarizes common degradation modes and distress symptoms that should be considered when assigning physical condition ratings to road components. When the field inspectors are unsure of how to rank the condition of some components, the details of component degradation should be recorded and photographed for referral to a civil engineer.

Table 6-5: Road Components Typical Degradation Modes and Condition Assessment Considerations

Main Component	Component Type	Degradation Modes	Distress Symptoms to Consider When Selecting Condition Rating
1. Formation	Earth work in flat, rolling or hilly terrain	Soil erosion, large cracks in earth or sinking of earth under the road (during earthquakes).	Severity of soil erosion or cracks or earth sinking and extent of earthwork required to restore the road formation.
2. Base Pavement	Aggregate (gravel layers)	Loss of strength and disintegration of aggregate under load, with exposure to moisture, deep potholes into sub-base layers.	Number and size of potholes per unit length in a road section.
3. Surface	Chip seal, asphalt or asphalt concrete	Oxidation of binding material, brittleness, flushing and bleeding, development of cracks, formation of potholes, reduction in skid resistance.	Severity of cracks and other surface layer defects per unit length in a road section
4. Curb and gutter	Concrete	Structural cracks in concrete and break up of curb.	Severity and number of defects in curb and gutter per unit length in a road section.
5. Drainage Sumps	Concrete, cast iron or steel	Structural cracks or blocked drains, corrosion of steel	Severity and number of drainage sump defects per unit length in a road section.
6. Footpath	Concrete	Cracks, spalling, rebar corrosion, deformation.	Number of and severity of structural cracks, Surface area affected by spalling, extent of rebar corrosion, extent of deformation.

6.4.Recommendations for Maintenance

The maintenance plan for roads should be developed as a new road is being designed and constructed. For maintaining records and performing inspections and maintenance, the road network should be divided into about 1-kilometer sections and records of inspections, maintenance and condition assessment should be kept for each section. A complete set of as-built plans and records of all maintenance operations and observations should be kept. The as-built plan should contain photographic records, location, and observations of any unstable conditions in relation to the road location, location of culverts, and other drainage features, and changes made to the road from original plan.

The maintenance requirements for roads include four specific types of activities, as described below:

i. Scheduled inspections and minor maintenance

Scheduled inspections and minor maintenance for sealed roads is recommended to be performed on a 2-year cycle. Recommended inspection and maintenance activities are listed below:

a. Inspect roads and footpath to identify potholes, cracks, damaged curbs and swales, and clogged sumps, allowing water to collect, and perform emergency repairs where required to avoid more serious damage and impairment to pavement.
b. Inspect roads to identify tree branches or brush overgrowth, which may interfere with safe traffic flow or safety of pedestrians, and trim trees where required.
c. Inspect road to identify abandoned vehicles or debris left along the rights-of-way, posing hazards to safe traffic flow, and remove such debris.

For unsealed roads, planned inspections and minor maintenance is performed once every 5 years to identify major impairments and identify need for regrading of the existing base or additional gravel in locations with serious soil erosion where the gravel base has eroded.

ii. Planned condition assessment

Planned condition assessment—performed once every 5 years—comprehensive condition assessment of all roads and footpaths to determine physical condition of the roads, curbs, drainage sumps and footpath and assess need for resealing, repaving or other repairs and their timing.

iii. Reactive maintenance

Reactive maintenance—to fix and repair potholes in roads, minor footpath defects that impact public safety, or clogged drainage sumps in specific locations in response to public complaints. During pothole repairs, road surfaces should be reworked as necessary to provide a smooth, driveable surface and a good crown or slope for drainage.

For unsealed roads, reactive maintenance involves fixing and repairing road base in locations, where such repairs are warranted immediately.

iv. Planned major repairs and refurbishment

Planned major repaving of roads or major repairs to footpaths, road curbs, or drainage systems. This involves repaving of the roads or major (capital) repairs to footpaths, road curbs, or drainage sumps found in poor or very poor condition. Some roads may involve strengthening the base and reconstruction of concrete curbs. Rutting and loss of ballast often occurs during rainy season use. A plan should be in place to provide ballast when necessary to maintain continued use of the road.

For unsealed roads, during planned major regrading, a grader on the first pass should move material from the shoulder to a windrow in the center of the roadway. On the second pass, the blade should be centered on the windrow and continue working along the roadway. The blade should be adjusted to provide a slight slope or crown and should avoid cutting too deep into the road surface.

6.5. Data Collection Requirements to Effectively Manage the Assets

The data collection requirements for asset management functions of roads are summarized in Table 6-6.

Table 6-6: Road Network Data Collection Requirements

Asset Hierarchy	Section ID
	Name of country
	Service sector
	Road category - local, secondary or primary collector, arterial
	Asset location - GPS coordinates (start section)
	Asset location - GPS coordinates (end section)
Construction Details	Length of the road section
	Average width of road the road section
	Number of lanes
	Terrain (flat, rolling, steep)
	Region (urban or rural)
	Base pavement thickness
	Surface pavement type - chipseal, asphalt, or asphalt concrete
	Does it have curb and gutter - on one side, both sides, none
	Does it have drainage sumps - how many in section?
	Does it have foot path - one side, both sides, none
	Width and thickness of foot path
Asset Component Condition	Condition of formation
	Basis for condition rating, if the rating is less than 3
	Condition of base pavement
	Basis for condition rating, if the rating is less than 3
	Condition of surface seal
	Basis for condition rating, if the rating is less than 3
	Condition of curb and gutter
	Basis for condition rating, if the rating is less than 3
	Condition of drainage sumps
	Basis for condition rating, if the rating is less than 3
	Condition of footpath
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional rating, if the rating is less than 3

Table 6-6: Road Network Data Collection Requirements (continued)

Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Unit cost for road formation - earthwork
	Unit cost for base-pavement
	Unit cost for surface seal
	Unit cost for curb and gutter
	Unit cost of drainage sump
	Unit cost for footpath
	Current replacement cost
	Annual maintenance cost
	Unit cost for substructure construction
	Unit cost for superstructure construction
	Unit cost for building envelope renewal
	Unit cost for service renewal

7. Bridges and Culverts—Condition Assessment

7.1. Main Components

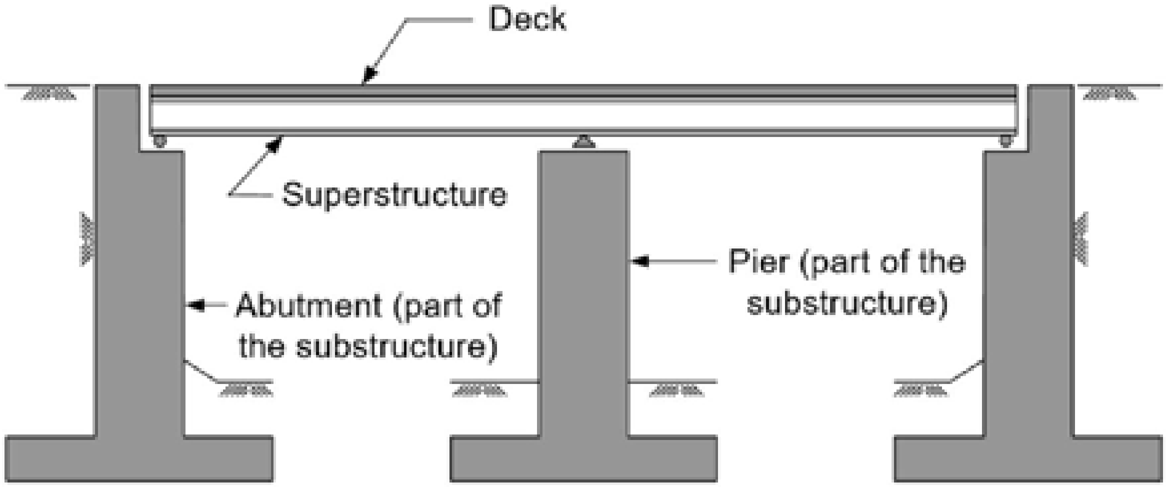
According to US National Bridge Inspection Standards, a bridge is a structure erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads and an opening measured along the center of the roadway of more than 6 meters (20 feet) between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes.

A culvert is generally a tunnel-like structure that allows water to pass under a roadway or railway. While piers and abutments are the supporting structures for a bridge, culverts are usually embedded in the soil which bears the major portion of the culvert load. When it is hard to distinguish between a culvert and a bridge, the deciding factors are the width of the structure.

As shown in Figure 7-1, a bridge has the following main components:

- substructure
- superstructure
- deck
- bridge bearing

Figure 7-1: Pavement Deflection Assessments Under Load

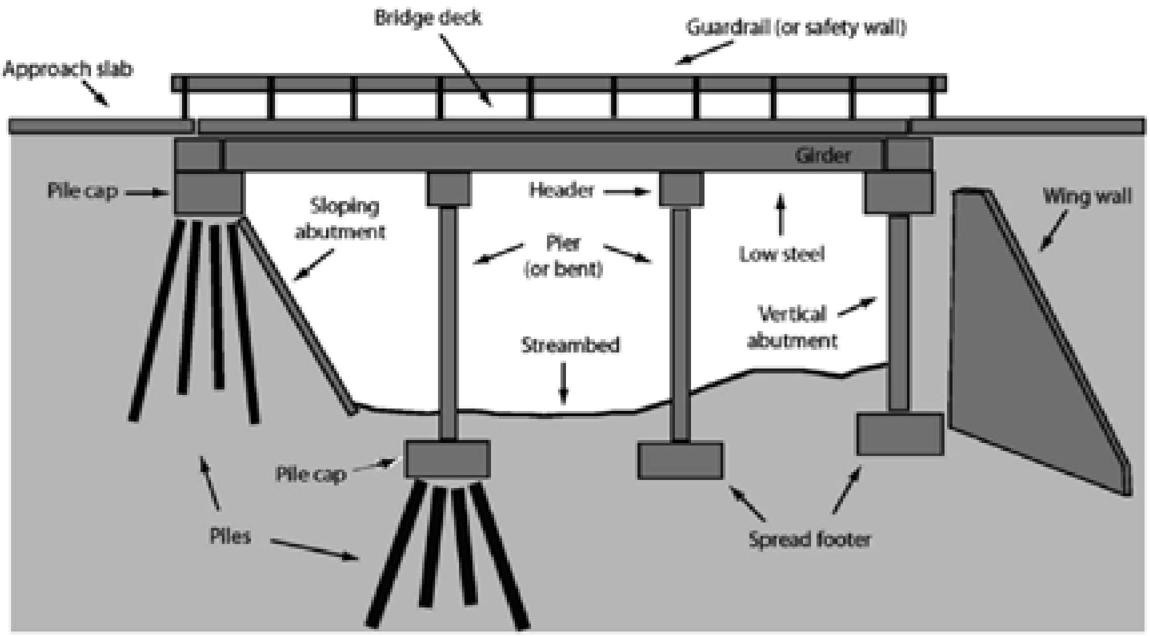


In a bridge, the substructure includes all components below the bearing and its purpose is to transfer loads from the superstructure to the foundation soil or rock. Substructures are divided into two basic categories:

- abutments
- piers

Abutments support the ends of the superstructure and the piers support the superstructure at intermediate points along the bridge spans, as shown in Figure 7-2.

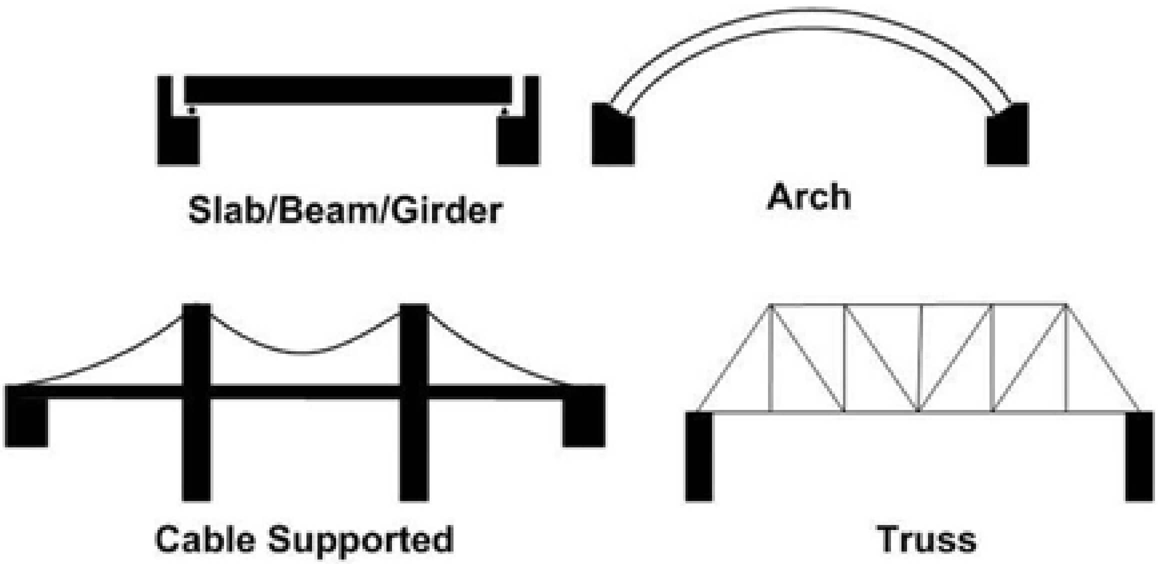
Figure 7-2: Substructure Components—Piers and Abutments



The superstructure is the bridge component supporting the deck or riding surface of the bridge, as well as all the live loads applied to the deck. The function of the superstructure is to span a feature and transmit forces from the deck to the substructure. Many different types of superstructure exist, but the following types of superstructure are more common, as shown in Figure 7-3:

- slabs
- single web beams/girders
- box beams/girders
- trusses
- arches
- cable-supported bridges

Figure 7-3: Bridge Superstructure Types



The deck supports the pavement to which live loads are directly applied and provides a smooth and safe riding surface for traffic over the bridge. The decks also employ joints to accommodate expansion, contraction, and rotation of the superstructure. In addition, the joint must provide a smooth transition from an approach roadway to the bridge deck or between adjoining segments of the bridge deck.

The bridge bearing serves as the interface between the superstructure and the substructure and has three primary functions. It transmits all loads from the superstructure to the substructure, permits longitudinal movement of the superstructure due to thermal expansion and contraction, and permits rotation caused by load deflection. Bearings that do not allow horizontal movement of the superstructure are referred to as fixed bearings. Bearings that allow horizontal movement of the superstructure are known as expansion bearings. Both fixed and expansion bearings permit rotation.

All main components of the bridge may be manufactured from timber, steel, and steel-reinforced concrete. Timber bridge members can be used to carry tension or compression loads and these are made into three basic shapes:

- round timber members which include piles, columns and posts;
- rectangular shaped members which include planks, beams, columns and piles; and
- built-up shapes for wood beams.

Concrete is the most commonly used material in bridge construction, because it can be formed into any shape to carry axial and bending loads. Since bending results in a combination of compressive and tensile stresses, concrete bending members are typically reinforced with either reinforcing steel bars or with prestressing steel in order to carry the tensile stresses in the member. Reinforcing steel is also added to increase the shear and torsion capacity of concrete members. Concrete structures can be either pre-cast in factories or poured in place at site.

Steel, due to its high strength and ease of manufacturing, is popular material for bridge construction. Rolled steel shapes commonly used on bridges include bars and plates, angle irons, channels, and beams. Different structural members are joined using a variety of fasteners, including pins, bolts and nuts, rivets, and welding,

A culvert is basically a structure design that permits water to flow efficiently across a roadway. Culverts can be considered small bridge, constructed entirely below and independent of the roadway surface and does not have a deck, superstructure, or substructure. In accordance with the National Bridge Inspection Standards definition, culverts covering longer than 6 meters road span are defined as a bridge. Culvert construction materials include concrete, masonry, steel, aluminum, timber, and plastic mouldings.

Figure 7-4: Typical Culvert

The typical useful life of bridges and culverts can vary broadly, based on the factor of safety employed in their design and the protective treatments used to delay the degradation of components. Bridge components manufactured from concrete or steel typically provide a longer service life than timber.

The typical service life of bridge components, based on the materials employed in their construction, are shown in Table 7-1. Table 7-2 provides typical useful life for complete bridge and culverts, employing different types of construction materials.

Table 7-1: Typical Useful Life—Bridge Components

Main Component	Component Type	Typical Useful Life
Bridge Substructure	Concrete	75 years
	Steel	75 years
	Timber	40 years
Bridge Superstructure	Concrete	75 years
	Steel	75 years
	Timber	40 years
Bridge Decking	Concrete	75 years
	Steel	75 years
	Timber	40 years

Table 7-2: Typical Useful Life—Bridges and Culverts

Asset Type	Predominant Construction Material	Typical Useful Life
Culvert	Concrete	75 years
	Steel	75 years
Bridge	Concrete and/or steel	75 years
	Timber	40 years

7.2. Typical Degradation Modes

Many different factors contribute to degradation of bridge components, including structural fatigue caused by live loads, use by heavy vehicles, physical and chemical damage in steel or steel-reinforced concrete bridges, corrosion and structural cracks in concrete members, and decay of wood fibers in timber bridges.

Sources of physical damage to steel-reinforced concrete structures include fire, earthquakes, abrasion, and expansion and contraction stresses, while chemical damage occurs due to corrosion caused by harsh environments. For concrete structures, cracking or spalling most commonly results from exposure to harsh environments, which degrades structures.

Figure 7-5: Degradation of Concrete in Bridges

The two most common causes of concrete corrosion are carbonation and salt attack. The alkaline conditions that naturally exist in concrete form a passive film on the surface of the steel reinforcing bars, preventing corrosion. However, reduction of the pH value caused by carbonation or ingress of chlorides causes this passive film to degrade, allowing the reinforcement to corrode in the presence of oxygen and moisture. Leaching of the alkalinity from concrete also lowers pH value to cause corrosion of steel reinforcement. As reinforcing bars rust, the volume of the rust products can increase up to six times that of the original steel, thus increasing pressure on the surrounding material, which slowly cracks the concrete. The most exposed elements usually deteriorate first, and it may take 5 to 15 years for the effects of reinforcing steel corrosion to become visibly noticeable. Cracks eventually appear on the surface and concrete starts to flake off or spall.

The corrosion of structural steel is an electrochemical process that requires the simultaneous presence of moisture and oxygen. Essentially, the iron in the steel is oxidized to produce rust, which occupies approximately six times the volume of the original material. The rate at which the corrosion progresses depends on several factors, but principally the micro-climate immediately surrounding the structure. Significant loss in cross section area of steel members eventually reduces their structural strength, leading to failure.

Timber bridges commonly employ glulam, which is a stack of would laminates joined with thin layers of glue. Several glulam stacks are glued together side by side to produce a wide range of cross-sectional sizes. Timber bridges, when exposed to harsh environmental conditions, deteriorate due to decay, insect attack, weathering, and mechanical damage, resulting in loss of structural strength.

Some other degradation modes for bridges include concrete shrinkage and creep, settlement of piers, misaligned bearing devices and expansion joints, substructure displacement, and rupture of tendons and cables; etc.

Concrete bridges are highly vulnerable during earthquakes. Bridges may also fail due to the uplift force during high flood levels. Table 7-3 shows the levels of vulnerability of bridges to typical natural disasters.

Table 7-3: Vulnerability of Bridges and Culverts to Damage from Natural Disasters

Natural Disaster	Vulnerability to Damage	Asset Components Most at Risk
Earthquake	High	Bridge substructure, superstructure or culverts made of concrete
Flooding	High	Bridge understructure or superstructure
Windstorm	None	

Source: Author created

7.3. Physical Condition Assessment Techniques

Condition assessment of bridges and culverts should be performed by an experienced structural engineer and commonly involves visual inspection and site measurement, structural analysis, and nondestructive testing to determine remaining useful life and/or structural strength of components.

The visual inspection of the bridges involve detailed close-up inspections of all bridge components to identify and measure:

- verification of dimensional details,
- deformation/deflection of the structural members,
- extent of corrosion of steel members,
- appearance of the concrete surfaces,
- presence of cracks, their appearance, and patterns,
- deterioration of the concrete and exposed rebars, and
- condition and alignment of bridge bearings.

The structural assessment involves:

- review of drawings and as-built construction records for substructure, superstructure, and decking;
- systematic examination of the substructure, superstructure, and decking to determine structural concerns, including structural defects, damage, deformation or deterioration of structural members;
- testing of materials used in construction to quantify their structural capacities and/or quantification of reduction in strength due to deterioration or defects; e.g., when the crossection area of a structural member is reduced due to corrosion or timber decay, its reduced strength should be calculated and compared with the design loads;
- structural analysis to confirm structural adequacy substructure, superstructure and decking of the bridge.

The nondestructive testing typically includes:

- Schmidt/rebound hammer test, used to determine the surface hardness of concrete,
- cover meter testing, used to measure the location of steel reinforcing bars beneath the surface of the concrete and to determine diameter of the reinforcing bars;
- carbonation depth measurement test, used to determine if moisture has penetrated the reinforcing bars and to identify if corrosion may be occurring;
- ultrasonic pulse velocity testing, used to measure the compressive strength of the concrete;
- penetration resistance or windsor probe test, used to measure the surface hardness and hence the strength of the surface and near surface layers of the concrete;
- permeability test, used to measure the flow of water through the concrete;
- radiographic testing, used to detect voids in the concrete and the position of stressing ducts;
- sonic methods using an instrumented hammer, providing both sonic echo and transmission methods and used to detect voids;
- infrared thermography, used to detect voids, delamination, and other anomalies in concrete;
- half-cell electrical potential method, used to detect the corrosion potential of reinforcing bars in concrete; and
- ground penetrating radar or impulse radar testing, used to detect the position of reinforcing bars or stressing ducts.

For timber bridges, nondestructive test techniques consists of:

- ultrasonic inspections, which involve analysis of the characteristics of high frequency stress waves propagating through wood to detect strength-reducing defects such as knots, slope of grain, and decay in wood members;
- drill resistance test used to determine wood density and detect decay timber;
- radiography to determine wood density and investigate wood degradation due to fungal attack;
- ground penetrating radar, used to determine wood density and wood decay;
- vibration tests, to determine modulus of elasticity and structural strength of wood.

Figures 7-5 and 7-6 show examples of bridges in poor condition. For concrete bridges, spalling has reduced the effective crosssection area of structural members and, in the steel bridge, severe rusting has reduced the crossection area of superstructure members. Only a detailed engineering analysis could determine the impact of reduced crosssection area on load carrying capacity of these bridges.

Figure 7-6: Bridges in Poor Condition

Table 7-4 summarizes the common degradation modes and distress symptoms that should be considered when assigning physical condition ratings to bridge components and culverts. When the field inspectors are unsure of how to rank the condition of some components, the details of component degradation should be recorded and photographed for referral to a civil engineer.

Table 7-4: Bridges and Culverts Degradation Modes and Condition Assessment Considerations

Main Component	Component Type	Degradation Modes	Distress Symptoms to Consider When Selecting Condition Rating
1. Bridge Sub Structure	Concrete	Cracks, spalling, rebar corrosion, deflection.	Number of and severity of structural cracks, depth and surface area of concrete affected by spalling, extent of rebar corrosion, extent of deformation.
	Steel	Corrosion, deflection, deformation.	Severity of corrosion, reduction in cross-section area due to corrosion, degree of deflection from vertical.
	Timber	Wood decay, termite damage, cracks, deflection.	Extent of damage from decay or termites, number of and severity of cracks, reduction in effective cross-section area and strength, degree of deflection from vertical.
2. Bridge Super Structure	Concrete	Cracks, spalling, rebar corrosion, deflection.	Number of and severity of structural cracks, depth and surface area affected by spalling, extent of rebar corrosion, extent of deformation.
	Steel	Corrosion, deflection, deformation.	Severity of corrosion, reduction in cross-section area due to corrosion, degree of deflection from vertical.
	Timber	Wood decay, termite damage, cracks, deflection	Extent of damage from decay or termites, number of and severity of cracks, reduction in effective cross-section area and strength, degree of deflection from vertical.
3. Bridge Decking	Concrete	Blisters, cracking, crazing, curling, delamination, efflorescence, low spots, popouts, scaling, or spalling.	Number of and severity of defects.
	Asphalt	Potholes, surface and baselayer deformation.	Number and severity of potholes and deformations.
	Timber	Wood decay, termite damage, cracks, deflection.	Extent of damage from decay or termites, number of and severity of cracks, reduction in effective cross-section area and strength, degree of deflection from vertical.
4. Culvert	Concrete	Cracks, spalling, rebar corrosion, deflection.	Number of and severity of structural cracks, depth and surface area affected by spalling, extent of rebar corrosion, extent of deformation.
	Steel	Corrosion, deflection, deformation.	Severity of corrosion, reduction in cross-section area due to corrosion, degree of deflection from vertical.

7.4. Recommendations for Maintenance

The maintenance plan for bridges and culverts should be developed when the new bridge or culvert is being designed and constructed. A complete set of as-built plans and records of all maintenance operations and observations should be kept. The maintenance requirements for roads include four specific types of activities:

i. Scheduled inspections and minor maintenance

Scheduled, annual inspections and minor maintenance for bridges and culverts is recommended. Recommended inspection and maintenance activities include:[11]

a. cleaning activities, including annual water flush of all decks, drains, bearings, joints, pier caps, abutment seats, concrete rails, and parapets each spring;
b. preventive maintenance such as painting, coating and sealant applications, and routine minor deck patching and railing repairs;
c. inspection of bearing systems, expansion joints, main structural members, including stringers, beams, piers, pier and pile cap, abutments and footings, underwater foundation structure, and applications of coatings and sealants, as required;
d. lubricating of mechanical bearing devices to prevent rusting and assist in their movement;
e. stream channel maintenance, including debris removal, stabilizing banks, and correcting erosion problems; and
f. maintaining effective drainage on bridge decks, because the deck structure and reinforcing steel is susceptible to corrosion.

ii. Planned condition assessment

Planned condition assessment—performed once every 5 years—comprehensive condition assessment of all bridges and culverts to determine their physical condition and assess need and timing of resealing, repaving, or other repairs.

iii. Reactive maintenance

Reactive maintenance—to carry out specialized structural repairs, including jacking up structures, structural crack repairs, epoxy injection, repairing or adjusting bearing systems, repair and sealing of expansion joints, repair or reinforcement of main structural members, including stringers, beams, piers, pier and pile cap, abutments and footings, underwater repairs, major deck repairs, and major applications of coatings and sealants.

iv. Planned major repairs and refurbishment

Planned major repaving of bridges and culverts includes renewal of substructure, superstructure, or deck members or bearings.

[11] Cambridge Systems, Inc. 2002. Transportation Asset Management Guide. Report prepared for the American Association of State Highway and Transportation Officials, Washington, DC.

7.5. Data Collection Requirements to Effectively Manage the Assets

The data collection requirements for asset management functions of buildings are summarized in Table 7-5.

Table 7-5: Bridge Data Collection Requirements

Asset Hierarchy	Bridge ID
	Name of country
	Service sector
	Bridge category - bridge or culvert
	Asset location - GPS coordinates (start section)
	Asset location - GPS coordinates (end section)
Construction Details	Length of the bridge section
	Average width of bridge section
	Number of lanes
	Bridge or culvert
	Substructure type (steel, concrete or timber)
	Superstructure type (steel, concrete or timber)
	Deck type (asphalt or concrete)
Asset Component Condition	Condition of superstructure
	Basis for condition rating, if the rating is less than 3
	Condition of substructure
	Basis for condition rating, if the rating is less than 3
	Condition of decking
	Basis for condition rating, if the rating is less than 3
	Condition of culvert
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction
	Unit cost for superstructure
	Unit cost for substructure
	Unit cost for deck
	Unit cost for culvert

8. Civil Aviation—Runways/Taxiways

8.1. Main Components

Civil aviation runways and taxiways consist of the following structural components:

- base pavement
- surface pavement
- drainage sumps
- security fence

In addition to these structural components, airport runways employ different types of aircraft navigation aids, which are not covered in this document.

The runway surface layer provides a hard, skid-free surface for safe aircraft landing and takeoff. The paved surface is graded laterally to allow rainwater to drain away from the runway centerline on to the grassed apron, without causing ponding on the runway surface. The runway is typically grooved for about 20 metres on either side of the center line, with surface grooves cut in the transverse direction to the pavement centerline, to make additional contribution to runway surface drainage. But the main purpose is to increase friction between the pavement surface and aircraft tires to reduce the possibility of hydroplaning, even when there is water on the runway. Runway grooving provides improved contact between aircraft tires and the pavement surface when water is present on the runway surface.

The runway and taxiways also have surface markings to provide visually displayed directions to the aircraft pilots during daytime landing conditions. Runway markings indicate the beginning and end of the designated space for landing and takeoff under non-emergency conditions.

The base pavement provides structural support to the surface layer and typically consists of compacted aggregate (gravel) of required thickness installed on top of graded earthworks. The drainage sumps are typically installed in the grassed apron next to the runway and these are installed to drain excess rainwater. The security fences keep out unauthorized persons or animals that could jeopardize aircraft safety and security.

The typical life of a runway can vary significantly in quality of surface and pavement, aircraft landing and take-off volume, effectiveness of drainage, and quality and scope of preventative maintenance. The runway and taxiway surface renewal for asphalt or asphalt concrete typically involves milling of the overlay and resurfacing of the top layer. Because only the top part of the surface layer is milled and resurfaced, the lower level of asphalt (layer beneath the milled depth) is considered the long-life component and the milled depth is considered the short-life component. The short useful life of the surface is the average time between the surface renewal treatments, e.g., mill and replace asphalt concrete. The long useful life for the surface is the time between complete runway reconstruction; it is estimated to be about five times the renewal cycle.

In Table 8-1, for runway surface and base pavement components, a short life and a long life is shown. This is because when the surface reaches the end of its life, before application of a new seal, the existing road seal material is removed through a milling operation. But during the milling operation, 100% of the original seal is not removed, but only the top portion of the seal is removed, and the lower portion remains in service. Similarly, when the base pavement reaches the end of its service life, only a fraction of the original pavement is ripped and removed and the lower portion of the base pavement remains in service.

The formation under the runway and taxiway pavement does not require any renewal and therefore is deemed to have indefinite life.

Table 8-1: Runway and Taxiway Components and their Typical Useful Life

Main Component	Component Type	Component Make up		Typical Useful Life	
		Long Life (%)	Short Life (%)	Long Life	Short Life
1. Base Pavement		20%	80%	120 years	60 years
2. Surface Pavement	Asphalt concrete	10%	90%	50 years	12 years
	Concrete	10%	90%	60 years	20 years
3. Drainage Sumps		n.a	100%	n.a	50 years
4. Security fence		n.a	100%	n.a	30 years

Table 8-2 indicates the typical useful life of the runway as a complete asset, which assumes that the runway will need to be reconstructed when the base pavement has reached the end of its life.

Table 8-2: Typical Useful Life—Runway and Taxiways

Asset	Typical Useful life
Runway or Taxiways	60 years

8.2. Typical Degradation Modes

For runway pavements, typical degradation mode is the oxidation of binding material, which gradually decreases the pavement strength and the pavement becomes brittle and starts to develop longitudinal or lateral cracks (Figure 8-1).

Figure 8-1: Runway Surface Degradation due to Cracks

Because impurities in form of vegetation are often present in the quarried material used for runway resurfacing, as time passes such vegetation begins to decay and pluck out, leaving imperfections in the surface, as shown in Figure 8-2.

Figure 8-2: Runway Surface Degradation due to Vegetation Plucking-Out

Similarly, if asphalt is paved over the base contaminated with vegetation, the vegetation would rot with time, causing failures that appear in the shape of volcano cracks (Figure 8-3). This type of defect is much more serious, because it extends through the entire surface layer into the base.

Figure 8-3: Runway Surface Degradation due to Volcano Cracks

Resealing of asphalt pavement prevents moisture from penetrating its surface. It also substantially slows oxidation of the underlying pavement. If the cracks in runway are resealed in a timely manner, it helps extend the service life of paving, but when the cracks are not resealed, the paved surfaces degrade more quickly.

For drainage sumps, the degradation mode is rusting of the steel grill or cracks in the concrete base. The drainage pipes may get chocked with leaves if not maintained in a timely manner.

For security fences, the common degradation mode is oxidation (rusting) of steel members with age, which gradually reduces the structural strength of the members, eventually leading to failure. Fence impairment may also be caused by damage due to motor vehicle accidents or due to vandalism.

If the entire runway is covered with cracks, as in Figure 8-3, it would indicate a runway in “poor” condition due to the presence of deep structural cracks.

Table 8-3 shows the level of vulnerability of runways to typical natural disasters.

Table 8-3: Vulnerability of Runways to Damage from Natural Disasters

Natural Disaster	Vulnerability to Damage	Asset Components Most at Risk
Earthquake	Medium	Base pavement and surface seal
Flooding	High	Base pavement and surface seal
Windstorm	None	

8.3. Physical Condition Assessment Techniques

Condition assessment of structural components of the air strip should be performed by a civil engineer. Condition assessment can be performed through visual inspection by carefully examining the condition of the pavement surfaces supplemented by *in-situ* testing,[12] if required.

In-situ testing with dynamic cone penetrometer, e.g., scala penetrometer or drop impact hammer (Clegg Hammer), or shear vane and test pit and hand auger investigations, as shown in Figure 8-4, can be used to further confirm the remaining strength of pavement.

Figure 8-4: Tools to Assess the Remaining Strength of Runway Pavement

The condition assessment of drainage sumps and security fences is performed through visual inspection.

Table 8-4 summarizes the common degradation modes and distress symptoms that should be considered when assigning physical condition ratings to runway/taxiway components. When the field inspectors are unsure of how to rank the condition of some components, the details of component degradation should be recorded and photographed for referral to a civil engineer.

Table 8-4: Runway/Taxiway Degradation Modes and Condition Assessment Considerations

Main Component	Component Type	Degradation Modes	Distress Symptoms to Consider When Selecting Condition Rating
1. Base Pavement	Aggregate (gravel layers)	Loss of strength and disintegration of aggregate under load, deformation (sinking) of base pavement, potholes into sub-base layers.	Number and size of potholes and other defects per unit surface area.
2. Surface	Asphalt or asphalt concrete	Oxidation of binding material, brittleness, flushing and bleeding, development of cracks, formation of potholes (in extreme cases), reduction in skid resistance.	Severity of cracks and other surface layer defects per unit surface area.
3. Drainage Sumps	Concrete, cast iron or steel	Structural cracks in sumps or blocked drains, corrosion of steel.	Severity and number of defects in drainage sumps.

[12] Government of Saskatchewan. n.d. Standard Test Procedures Manual. Foundation Investigation. Saskatchewan Highways and Transportation. Regina.

Table 8-4: Runway/Taxiway Degradation Modes and Condition Assessment Considerations (continued)

Main Component	Component Type	Degradation Modes	Distress Symptoms to Consider When Selecting Condition Rating
4. Security Fence	Steel	Corrosion, deflection of posts, broken mesh, missing panels.	Severity of corrosion, reduction in cross-section area due to corrosion, degree of deflection from vertical, affected mesh area with defects.
5. Drainage Sumps	Concrete, cast iron or steel	Structural cracks or blocked drains, corrosion of steel	Severity and number of drainage sump defects per unit length in a road section.
6. Footpath	Concrete	Cracks, spalling, rebar corrosion, deformation.	Number of and severity of structural cracks, surface area affected by spalling, extent of rebar corrosion, extent of deformation.

8.4. Recommendations for Maintenance

To plan for airport runway maintenance needs, it is important to keep a complete set of as-built plans and records of all maintenance operations and observations. The as-built plan should contain the complete history of the project from planning to construction, photographic records, location, and observations of any unstable conditions, wet areas that may have required additional excavation and replacement with more suitable ballast backfield materials, and all major changes made to the original plan. The most valuable tool for the maintenance program is the knowledge and experience gained by individuals performing the maintenance.

Specific activities during each of the four types of maintenance categories include:

i. Scheduled inspections and minor maintenance

Scheduled inspections and minor maintenance are recommended to be performed once a year. Recommended inspections and maintenance activities are listed below:

a. Perform airstrip inspections to identify potholes, cracks, and depressions in runway surface, which would interfere with safe landings or takeoff of aircraft and perform emergency repairs, as needed.
b. Perform airstrip inspections to identify locations with poor water drainage, which would lead to ponding on airstrip surfaces during heavy rain and perform emergency repairs, where required, to avoid more serious damage and impairment to pavement.
c. Perform airstrip inspections to identify locations of brush overgrowth along the airstrip, which may interfere with safe movement of aircraft and perform brush clearing where required.
d. Perform inspections of airstrip markings and repaint surfaces where the markings have faded away.
e. Perform inspections of the security fences to confirm their effectiveness in blocking entry of unintended animals and vehicles during aircraft movement.

ii. Planned condition assessment

Planned condition assessment—performed once every 3 years—comprehensive condition assessment of the runway to determine physical condition of the pavement to determine its remaining useful life and assess need for resealing or repaving and its timing. Air navigation equipment is inspected by qualified contractors following strict procedure and schedule dictated by International aviation standards and safety protocols.

iii. Reactive maintenance

This involves performing repairs to the runway, the drainage system or security fences, in specific locations, to rectify identified defects and impairment.

iv. Planned Major Repairs and Refurbishment:

This involves repaving of the runway when conditions reach poor or very poor or capital repairs are needed to the security fences or drainage system.

8.5.Data Collection Requirements to Effectively Manage the Assets

The data collection requirements for asset management functions of runways are summarized in Table 8-5.

Table 8-5: Runway/Taxiway Data Collection Requirements

Asset Hierarchy	Runway section ID
	Name of country
	Service sector
	Runway category - runway, taxiway or hard stand area
	Asset location - GPS coordinates (start section)
	Asset location - GPS coordinates (end section)
Construction Details	Length of the runway section
	Average width of runway section
	Base pavement thickness
	Surface pavement type
	Number of drainage sumps
	Height of security fence
	Length of security fence
Component Condition	Condition of base pavement
	Basis for condition rating, if the rating is less than 3
	Condition of surface seal
	Basis for condition rating, if the rating is less than 3
	Condition of drainage sumps
	Basis for condition rating, if the rating is less than 3
	Condition of security fence
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Unit cost for base-pavement
	Unit cost for surface seal
	Unit cost of drainage sump
	Unit cost for security fence

9. Wharfs and Jetties

9.1. Main Components

The role of a commercial port is to facilitate loading and unloading of cargo by allowing docking of large ships and boats. When a reef blocks a ship's path to the dock, channels are required to be cut through the reef to allow safe passage of the ship or boat to the dock. In addition to the commercial ports, most island countries also have boat harbours, which are used as boat launching facilities for fishing or recreation.

Large commercial ports commonly employ wharfs, shown on the left in Figure 9-1, which is a structure along a coast, with multiple berthing facilities for docking. Wharfs typically employ a fixed platform supported on pilings. Smaller ports may employ jetties (Figure 9-1, right side), a structure that projects from the land into water for sufficient depth to where ships or boats can dock for loading and unloading.

Figure 9-1: Typical Wharf (left) and Jetty (right)

Source: Author provided

The components of seaport wharfs and jetties include the support structure and decking. Support structures typically consist of underwater substructures in the form of seawalls, beams, and piles or pillars. The support structure provides structural support for decking to allow loading and unloading of ships. The support structures are typically manufactured from steel-reinforced concrete or concrete-encased steel pillars and beams. Vertical seawalls along ocean fronts are padded with cushions to prevent damage to boats and ships from collisions with concrete structures during docking. Decking supports the loading and unloading surfaces, which are commonly paved with reinforced concrete or asphalt, but, for a jetty, the surface may be finished with timber.

Commercial ports and boat harbors may also require approach channels, mooring systems, and fixed cranes, but these assets are not included in this document.

The typical service life of the above listed components of a port or boat harbour, based on the commonly employed materials in their construction, are shown in Table 9-1.

Table 9-1: Typical Useful Life—Seaport or Boat Harbor Wharf or Jetty Components

Wharf or Jetty Components	Component Type	Typical Useful Life (Years)
Support Structures	Steel reinforced concrete	80 years
	Pressure treated timber	40 years
Decking	Concrete or asphalt concrete	40 years
	Pressure treated timber	20 years

Table 9-2 indicates the typical useful life of the wharf or jetty as a complete asset, which assumes that the wharf or jetty will need to be reconstructed when the support structure has reached the end of its life.

Table 9-2: Typical Useful Life—Wharf or Jetty

Asset	Typical Useful Life
Wharf or Jetty (Steel reinforced concrete structure)	80 years
Wharf or Jetty (Timber structure)	40 years

Source: Author created

9.2. Typical Degradation Modes

A typical degradation mode for a concrete wharf structure involves concrete spalling and rusting of steel rebar in structural members or corrosion of steel support pillars (Figure 9-2).

Figure 9-2: Concrete Structure in Very Poor (Badly Corroded and Rebar Exposed)

Because these structures are exposed to extremely corrosive conditions, anticipated high corrosion rates are considered during structural design and compensated with selection of greater safety margins. Degradation of structural strength also occurs due to metal fatigue induced by cyclic or dynamic loads. Degradation mechanisms related to metal loss and fatigue are typically time dependent and determine the maximum service life of the wharfs and jetties. The structure may also experience damage from repeated ship impacts.

Figure 9-3: Timber Structure of Jetty in Very Poor Condition (Reduced Diameter of Pillars due to Wood Rot)

Deterioration of timber usually occurs in two forms—warpage and wood rot. Warpage of timber is extremely common and results when the moisture content of the wood fluctuates. Wood rot reduces the cross-sectional area of structural members reducing their strength, eventually leading to failure.

Figures 9-2 and 9-3 both indicate wharf structures in poor condition, requiring engineering analysis to determine structural safety of the structures. Table 9-3 shows the level of vulnerability of wharf and jetties to typical natural disasters.

Table 9-3: Vulnerability of Wharfs and Jetties to Damage from Natural Disasters

Natural Disaster	Vulnerability to Damage	Asset Components Most at Risk
Earthquake	High	Concrete structure and concrete decking
Flooding	Low	
Windstorm	None	

9.3. Physical Condition Assessment Techniques

Condition assessment of ports and harbors should be performed by an experienced structural engineer and commonly involves visual inspection and site measurement, structural analysis, and nondestructive testing to determine remaining useful life and/or structural strength of components.

The visual inspection of wharfs and jetties involves detailed close-up inspections of structural components and decking to identify and measure:

- verification of dimensional details;
- deformation/deflection of the structural members;
- extent of corrosion of steel members;
- appearance of the concrete surfaces;
- presence of cracks, their appearance and patterns;
- deterioration of the concrete and exposed rebars; and
- extent of wood rot and remaining structural strength.

The structural assessment involves:

- review of drawings and as-built construction records for structures and decking;
- systematic examination of the structure and decking to determine structural concerns, including structural defects, damage, deformation, or deterioration of structural members;
- testing of materials used in construction to quantify their structural capacities and/or quantification of reduction in strength due to deterioration or defects; e.g., when the crosssection area of a structural member is reduced due to corrosion or timber decay, its reduced strength should be calculated and compared with the design loads; and
- structural analysis to confirm structural adequacy substructure, superstructure and decking of the bridge.

The nondestructive testing typically include:

- Schmidt/rebound hammer test, used to determine the surface hardness of concrete;
- cover meter testing, used to measure the location of steel reinforcing bars beneath the surface of the concrete and to determine diameter of the reinforcing bars;

- carbonation depth measurement test, used to determine if moisture has penetrated the reinforcing bars and to identify if corrosion may be occurring;
- ultrasonic pulse velocity testing, used to measure the compressive strength of the concrete;
- penetration resistance or windsor probe test, used to measure the surface hardness and hence the strength of the surface and near surface layers of the concrete;
- permeability test, used to measure the flow of water through the concrete;
- radiographic testing, used to detect voids in the concrete and the position of stressing ducts;
- sonic methods using an instrumented hammer, providing both sonic echo and transmission methods and used to detect voids;
- infrared thermography, used to detect voids, delamination, and other anomalies in concrete;
- half-cell electrical potential method, used to detect the corrosion potential of reinforcing bars in concrete; and
- ground penetrating radar or impulse radar testing, used to detect the position of reinforcing bars or stressing ducts.

For timber structures, nondestructive test techniques consists of:

- ultrasonic inspections, which involve analysis of the characteristics of high frequency stress waves propagating through wood to detect strength-reducing defects such as knots, slope of grain, and decay in wood members;
- drill resistance test used to determine wood density and detect decay timber;
- radiography to determine wood density and investigate wood degradation due to fungal attack;
- ground penetrating radar, used to determine wood density and wood decay; and
- vibration tests, used to determine modulus of elasticity and structural strength of wood.

Table 9-4 summarizes the common degradation modes and distress symptoms that should be considered when assigning physical condition ratings to wharfs and jetty components. When the field inspectors are unsure of how to rank the condition of some components, the details of component degradation should be recorded and photographed for referral to a civil engineer.

Table 9-4: Wharfs/Jetties Degradation Modes and Condition Assessment Considerations

Wharf or Jetty Components	Component Type	Degradation Modes	Distress Symptoms to Consider When Selecting Condition Rating
Support Structures	Steel reinforced concrete	Cracks, spalling, rebar corrosion, deflection.	Number and severity of structural cracks, depth and surface area of concrete affected by spalling, extent of rebar corrosion, extent of deformation.
	Pressure treated timber	Wood decay, abrasion damage, cracks, deflection.	Extent of damage from decay or abrasion, number of and severity of cracks, reduction in effective cross-section area and strength, degree of deflection from vertical.
Decking	Concrete	Blisters, cracking, crazing, curling, delamination, efflorescence, low spots, popouts, scaling, or spalling.	Number and severity of defects.
	Asphalt concrete	Oxidation of binding material, brittleness, flushing and bleeding, development of cracks, formation of potholes, reduction in skid resistance.	Severity of cracks and other surface layer defects per unit length in a road section.
	Pressure treated timber	Wood decay, cracks, deflection.	Extent of damage from decay, number and severity of cracks, reduction in effective cross-section area and strength.

9.4. Recommendations for Maintenance

The maintenance plan for wharfs and boat harbors should be tailored to their specific design and construction and therefore the maintenance plan should be developed when a new wharf, jetty, or channel is being designed and constructed. It is important to keep a complete set of as-built plans and records of all maintenance operations and observations.

The maintenance activities for wharfs and jetties require four types of maintenance activities:

i. Scheduled inspections and minor maintenance

Scheduled inspections and minor maintenance should be performed once a year. Since the concrete structures employed in wharfs generally employ complex designs, the inspections should be performed using a plan developed by the subject matter expert (structural engineer). The following is check list of activities to be included in planned inspections and minor maintenance:

a. visual inspection of concrete structures, including foundation piles or pillars to identify and measure the size of surface cracks, spalling, rust staining, and exposed rebar;
b. visual inspection of steel members to identify and quantify the degree of corrosion, pitting, mechanical damage, or reduction in cross-section due to corrosion;
c. visual inspection of timber components to identify the extent of wood rot or deformation due to warpage;
d. inspection of bumper pads to identify damage;
e. visual inspection of paved areas to identify and benchmarks surface conditions, potholes, drainage condition;
f. inspection of mooring systems to confirm the buoy and its topside hardware, fenders, and chafing strips are in satisfactory condition and to verify that the mooring has not been dragged from its proper location;
g. inspection of safety railings to identify the degree of damage or corrosion; and
h. inspection of access channels to confirm adequate depth for safe ship movement to the port.

ii. Planned condition assessment

Planned condition assessment of wharf structures, mooring systems, and approach channels should be performed by a structural engineer with expertise in marine structures, once every 5 years—it should include both above water and underwater inspections supplemented with non-destructive tests to benchmark the degree of corrosion on steel members and degradation of concrete structures and to identify serious structural deficiencies and defects in structures, requiring structural repairs or refurbishment and renewal of structural components.

iii. Reactive maintenance

Reactive maintenance involves site specific repairs, refurbishment, or renewal to address deficiencies, prevent further impairment of structures, and to ensure the structures continue to meet the functional requirements.

iv. Planned major repairs and refurbishment

Planned major repairs involve repaving of the wharf surfaces or major repairs to structures or re-dredging of the channels to remove silt. The specifications for such repairs must be prepared by subject matter expert with experience in marine structures.

9.5. Data Collection Requirements to Effectively Manage the Assets

The data collection requirements for asset management functions of commercial ports and boat harbors are summarized in Table 9-5.

Table 9-5: Wharfs and Jetties Data Collection Requirements

Asset Hierarchy	Commercial port/boat harbor ID
	Name of country
	Service sector
	Category - wharf or jetty
	Facility location - GPS coordinates (start section)
	Facility location - GPS coordinates (end section)
Construction Details	Length of the wharf or jetty
	Average width of wharf or jetty
	Number of shipping berths
	Structure type - concrete/steel/timber
	Deck Type - concrete/asphalt/timber/other
Asset Component Condition and remaining Service potential	Condition of structure
	Basis for condition rating, if the rating is less than 3
	Condition of decking
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional performance Rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction
	Unit cost for structure
	Unit cost of decking

10. Coastal Protection Structures

10.1. Types of Coastal Protection

Coastal protection in the form of seawalls or rock revetments are provided to protect the coastal districts from flooding, caused by ocean waves and more specifically to protect high value assets, i.e., roads, buildings, aviation assets, electricity or telecommunication assets, etc., from damage. Coastal protection is also provided to prevent shoreline erosion.

The following three types of coastal protections are commonly employed.[13] Only the first two types are currently used in Nauru.

i. Immobile (rigid) structures

These are vertical, sloping, or stepped structures, as shown in Figure 10-1 and are constructed of mass concrete or reinforced concrete, grouted rock or blocks. They require a well-founded toe on hard substrate to avoid scour and undermining. The structures must be strong to withstand high wave loading. Because they do not dissipate wave energy effectively (the structures are rigid and do not move), overtopping incidents are high.

These rigid structures offer hard defense against sea waves and are constructed with the primary purpose of reducing the impacts of tides and waves. This type of coastal protection has high capital cost and is used to protect costly assets along the coastline from the effects of erosion and/or flooding. Seawalls are constantly subjected to impacts of the sea—accentuated by climate change. Therefore, ongoing monitoring, maintenance and eventually replacement are requirements if seawalls are to provide effective long-term defenses. Seawall designs must take account of surrounding environment including landforms, wave climate, and so on. They can be standalone structures or form part of a combined structure with other assets, for example, wave walls along the crest of revetments.

ii. Semi-mobile structures

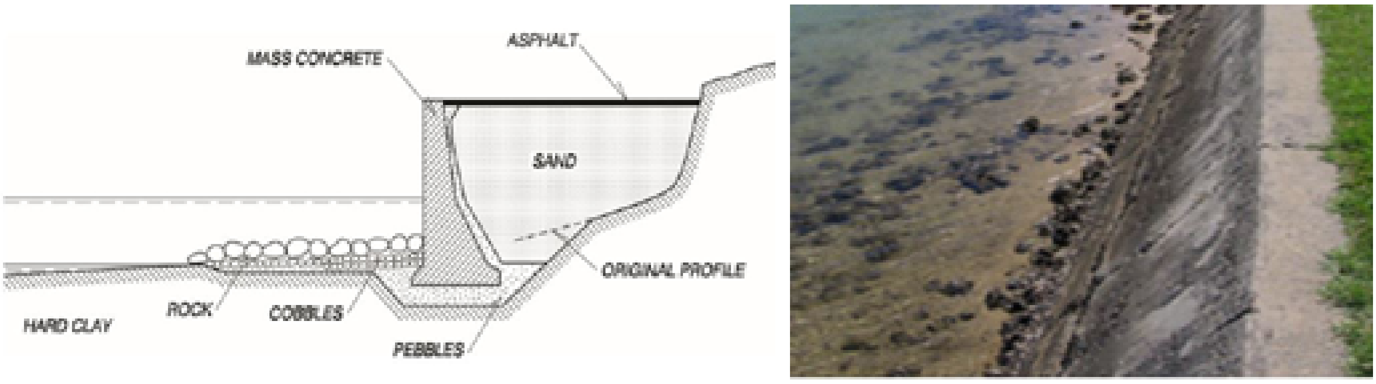
Semi-mobile structures are not firmly attached to the ground and can move under wave pressure, which helps dissipate some of the wave energy. If earth under the structure settles, the structure moves to new seabed location, without getting cracked or damaged. Semi-rigid structures are therefore better suited in regions with higher waves. Figure 10-2 shows some examples of the semi-rigid structures:

- rock revetments
- sand-filled geotextile bags held under gravity.

Rock revetment protection typically consists of an armoring layer applied to a sloping surface of an embankment or shoreline to reduce soil erosion by sea waves.

[13] Pacific Regional Infrastructure Facility (PRIF). 2017. Affordable Coastal Protection in the Pacific Islands. Prepared by Tonkin & Taylor International Ltd. New Zealand. pp20-21

Figure 10-1: Vertical Sea Wall Fixed Structure



Source: PRIF, 2017. Affordable Coastal Protection in the Pacific Islands, p.20.

Figure 10-2: Semi Rigid Structures—Sand Filled Bags and Rock Revetments

Source: PRIF, 2017. Affordable Coastal Protection in the Pacific Islands, p.20.

iii. Dynamic structures

Dynamic coastal protection structures involve artificial addition of sand or gravel to the coast to improve the capacity of a beach to act as a buffer against storm erosion or storm surge to protect the land behind. Sand replenishment or beach nourishment projects are examples of dynamic structures. When a wave strikes a dynamic structure, the structure moves to alter its shape and, in so doing, absorbs the wave energy. Dynamic materials continue to be moved over time with some loss of sand or gravel. Therefore, coastal protection using dynamic materials must include adequate build up to allow gradual material loss over time. Rock and gravel, which are also commonly used in mobile structures are generally less mobile than sand and therefore require less ongoing maintenance.

The typical useful life of different types of coastal protection structures is shown in Table 10-1. As shown, the useful life of dynamic structures can vary over a broad range, depending on the wave intensity.

Table 10-1: Typical Useful Life—Coastal Protection

Coastal Protection Asset	Asset Type	Typical Useful Life
Immobile (Rigid Structures)	Steel reinforced concrete walls	60 years
	Grouted rock or masonry walls	50 years
Semi-Mobile Structures	Rock revetments	40 years
Mobile Structures	Sand beach	15 years
	Rock and gravel beach	25 years

10.2. Typical Degradation Modes

Typical degradation modes for each of the three forms of coastal protection include:

i. Rigid structures

Rigid structures do not bend, but they will break when subjected to forces beyond their design limit. When storm surge force exceeds the structural strength of the structure, it can cause structural cracks. High waves can overtop the structure, completely destroying the seawall. In general, rigid structures are less prone to gradual degradation in strength but they fail suddenly under storm surge.

ii. Semi-mobile structures

Semi-mobile structures will bend but not break. They are less likely to suffer total failure during wave overtopping, but parts of the structure may get washed away or displaced, requiring maintenance after major storm events.

iii. Mobile structures

The mobile structures undergoing erosion will require periodic rehabilitation, timing depending on the strength of wave activity.

10.3. Physical Condition Assessment Techniques

Condition assessment of the rigid structures should be carried out by a structural engineer and it may involve visual inspection, site measurement, and structural analysis. Because part of the structure is hidden underwater, inspections need to be performed of both above-grade and below-grade structure.

The visual inspection involve detailed close-up inspections of structural components and decking to identify and measure:

- verification of dimensional details,
- deformation/deflection of the structural members,
- extent of corrosion of steel members,
- appearance of the concrete surfaces,
- presence of cracks, their appearance and patterns, and
- deterioration of the concrete and exposed rebars.

In case of significant damage to the structure, the remaining strength of the concrete would need to be determined through testing. When a portion of the soil from under the footings has washed away, bearing strength of the soil may need to be examined. The structural assessment involves:

- review of drawings and as-built construction records for structures and decking;
- systematic examination of the structure to determine structural concerns, including structural defects, damage, deformation or deterioration of structural members;
- testing of materials used in construction to quantify their structural capacities and/or quantification of reduction in strength due to deterioration or defects; e.g., when the crossection area of a structural member is reduced due to corrosion, its reduced strength should be calculated and compared with the design loads; and
- structural analysis to confirm structural adequacy substructure, superstructure, and decking of the bridge.

Nondestructive testing typically includes:

- Schmidt/rebound hammer test, used to determine the surface hardness of concrete;
- cover meter testing, used to measure the location of steel reinforcing bars beneath the surface of the concrete and to determine the diameter of the reinforcing bars;
- carbonation depth measurement test, used to determine if moisture has penetrated the reinforcing bars and to identify if corrosion may be occurring;
- ultrasonic pulse velocity testing, used to measure the compressive strength of the concrete;
- penetration resistance or windsor probe test, used to measure the surface hardness and hence the strength of the surface and near surface layers of the concrete;
- permeability test, used to measure the flow of water through the concrete;
- radiographic testing, used to detect voids in the concrete and the position of stressing ducts;
- sonic methods using an instrumented hammer, providing both sonic echo and transmission methods and used to detect voids;
- infrared thermography used to detect voids, delamination, and other anomalies in concrete;
- half-cell electrical potential method: used to detect the corrosion potential of reinforcing bars in concrete; and
- ground penetrating radar or impulse radar testing, used to detect the position of reinforcing bars or stressing ducts.

Condition assessment of the semi-mobile and mobile structures can be completed by a civil engineer through visual inspection and dimensional measurement to determine the loss of material during a storm.

Figure 10-3: Seawalls in "Poor" Condition due to Structural Damage

Figure 10-4: Rock Revetment in “Poor” Condition due to Erosion

Figure 10-5: Sand Beach in “Poor” Condition due to Erosion

Table 10-2 shows the level of vulnerability of wharfs and jetties to typical natural disasters.

Table 10-2: Vulnerability of Coastal Protection to Damage from Natural Disasters

Natural Disaster	Vulnerability to Damage	Asset Components Most at Risk
Earthquake	High - rigid structures medium - semi mobile structures no risk to mobile structures	Rigid structures (i.e, seawalls)
Flooding	Rigid structures - medium mobile and semi-mobile - high	Mobile and semi-rigid structures.
Windstorm	None	

Source: Author created

Table 10-3 summarizes the common degradation modes and distress symptoms that should be considered when assigning physical condition ratings to wharfs and jetties components. When the field inspectors are unsure of how to rank condition of some components, the details of component degradation should be recorded and photographed for referral to a civil engineer.

Table 10-3: Coastal Protection's Degradation Modes and Condition Assessment Considerations

Coastal Protection Asset	Asset Type	Degradation Modes	Distress Symptoms to Consider When Selecting Condition Rating
Immobile (Rigid Structures)	Steel reinforced concrete walls.	Cracks, spalling, rebar corrosion, deflection or deformation.	Number of and severity of structural cracks, depth and surface area of concrete affected by spalling, extent of rebar corrosion, extent of deflection or deformation.
	Grouted rock or masonry.	Cracks, missing rocks, deflection, deformation.	Number of and severity of structural cracks, Surface area affected by defects or missing rocks, degree of exposure to overtopping of structure by waves.
Semi-Mobile Structures	Rock revetments.	Soil erosion at the base, displacement of rocks, deformation of structure.	Extent of coastal protection area adversely affected.
Mobile Structures	Sand beach.	Soil erosion.	Extent of coastal protection area adversely affected.
	Rock and gravel beach.	Soil erosion.	Extent of coastal protection area adversely affected.

10.4. Recommendations for Maintenance

The maintenance activities for coastal protection structures, including seawalls or rock revetments, requires the following four types of maintenance activities:

i. Scheduled inspections and minor maintenance

Scheduled inspections and minor maintenance—should be performed annually and it should include visual inspection and minor maintenance of both engineered and masonry seawalls, as well as rock revetments. It should consist of the following specific activities:

a. For engineered concrete seawalls or masonry walls, visual inspection should be performed annually with the objective of identifying incidents of damage, either in form of structural cracks, concrete spalling, exposed re-bar, missing section of the masonry wall or soil erosion at the base of the wall, caused by wave action or incidents of overtopping of the seawall by strong waves.
b. For rock revetments annual inspections should be performed to determine if the rock revetments have moved from their original location or if earth under the structure has settled or eroded away or if section of the rock revetment has been washed away by wave action.
c. Any minor damage that is repairable using maintenance budget and local resources should be repaired during routine maintenance.
d. When severe structural damage is identified during visual inspection, it should use a trigger to perform a more detailed inspection by a structural engineer.

ii. Planned condition assessment

The planned condition assessment for the seawall structures should be performed by a structural engineer with expertise in marine structures and should involve detailed inspections, measurement of the extent of structural damage that has occurred to the seawalls, and development of a plan to repair the damage and address the deficiencies to curb additional impairment to the structures and ensure they continue to provide their intended functions. The recommended mitigation measures may involve reactive maintenance to be performed immediately to address public safety concerns and/or comprehensive mitigation measures as a permanent solution.

iii. Reactive maintenance

Reactive maintenance involves immediate site-specific minor repairs, refurbishment, or renewal to address deficiencies, prevent further impairment of structures, and to ensure the structures continue to meet the functional requirements, following plans developed in step (ii).

iv. Planned major repairs and refurbishment

Planned major repairs involve major capital repairs and renewal of the seawalls to comprehensively address all deficiencies to ensure the structures continue to meet the functional requirements, following plans developed in step (b).

10.5. Data collection requirements to effectively manage the assets

The data collection requirements for asset management functions of buildings are summarized in Table 10-4.

Table 10-4: Coastal Protection Data Collection Requirements

Asset Hierarchy	Coastal protection ID
	Name of country
	Service sector
	Coastal protection category
	Facility location - GPS coordinates (start section)
	Facility location - GPS coordinates (end section)
Construction Details	Length of the coastal protection structure
	Height of the coastal protection structure
	Average thickness of the coastal protection structure
	Type of materials used for coastal protection
Asset Component Condition	Condition of coastal protection
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional performance rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction
	Unit cost for structure

11. Water Supply and Sewage Disposal Assets

11.1. Main Infrastructure Assets

In Pacific countries, public sector water and sanitation systems typically employ the following infrastructure assets:

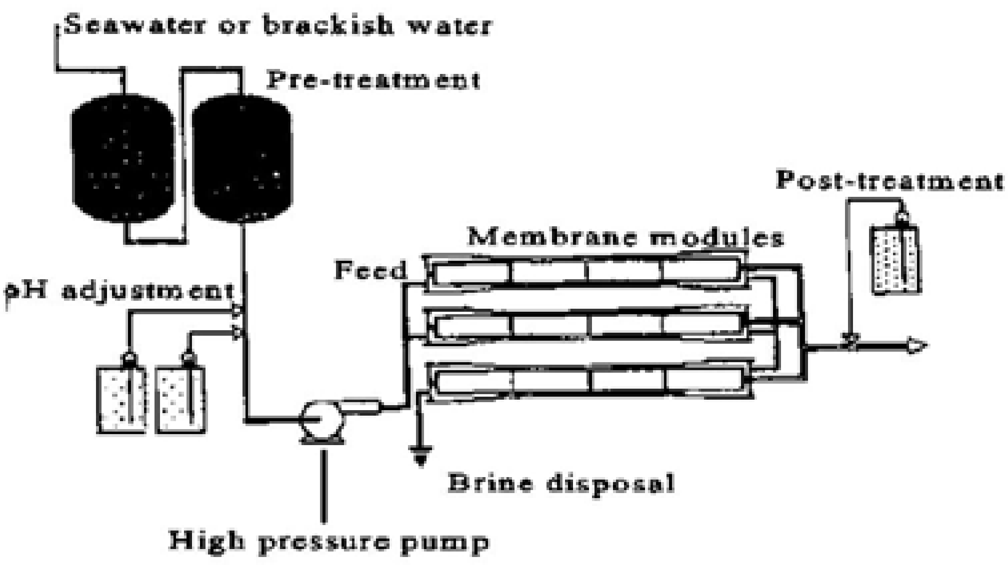
- water production facilities (desalination plant)
- rainwater harvesting equipment
- water storage tanks
- water pumping stations
- water distribution pipes
- sanitary sewer pipes and manholes
- sewage treatment plant.

Only a small fraction people in Pacific countries have access to piped water service, and many small countries employ water tanker trucks to deliver freshwater into household water tanks. Similarly, a significant share of people have no access to sanitary sewer systems, and employ septic tanks at the household level that are periodically pumped out by sewage pump trucks. Condition assessment of motor vehicles, including water tanker trucks and sewage pump trucks, is not covered by this document.

i. Typical water production facilities—desalination plant

Figure 11-1 shows the construction details of a desalination plant, with reverse osmosis technology.

Figure 11-1: Water Desalination Plant (reverse osmosis)



Desalination plants, which remove salt from seawater to make if fit for drinking, can use several different technologies to do so. They work on the principle of reverse-osmosis and are commonly used these days because they employ modern and energy efficient technology.

The system has the following key components:

a. Pre-treatment: Incoming water is pretreated by passing it through a membrane which removes suspended solid particles. During pre-treatment, pH level is adjusted, and a threshold inhibitor is added to control scaling caused by constituents in water, such as calcium sulphate.
b. Pressurization: Water pressure of the pretreated feed is increased by a pump to an operating pressure appropriate for the membrane and the salinity of the feed water.
c. Separation: When water passes through the permeable membranes they inhibit the passage of dissolved salts while permitting the desalinated water to pass through. Applying feed water to the membrane assembly results in a freshwater product stream and a concentrated brine reject stream. Because no membrane is perfect in its rejection of dissolved salts, a small percentage of salt passes through the membrane and remains in the water.
d. Stabilization: The clean water produced from the membrane assembly usually requires pH adjustment and degasification before being transferred to the distribution system for use as drinking water. The product passes through an aeration column in which the pH is elevated from a value of approximately 5 to a value close to 7. This water is discharged into storage tanks.

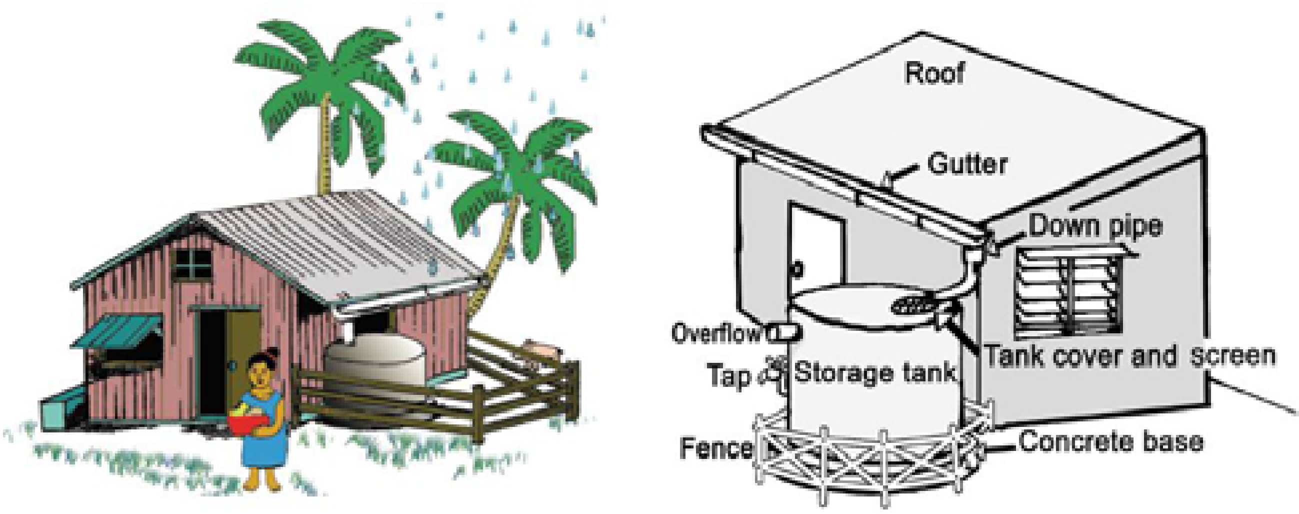
ii. Rainwater harvesting equipment

Rainwater harvesting, shown in Figure 11-2, is the primary source of water supply in some Pacific countries, such as Tuvalu. A rainwater harvesting system has the following components:[14]

a. Gutters installed along the building facia, which collect water from the roof;
b. Water tanks to store water;
c. Down-pipes which carry the water from the gutters to the storage tank; and
d. Course filter at the tank inlet.

In such systems, plastic gutters are attached to the building fascia with nails and a plastic downpipe collects the water from the gutters and delivers it into the storage tank through gravity.

Figure 11-2: Rainwater Harvesting—System Components



Source: SOPAC, 2004

[14] South Pacific Applied Geoscience Commission (SOPAC), 2004. Harvesting the Heavens: Guidelines for Rainwater Harvesting in Pacific Island Countries. Suva.

iii. **Water storage tanks**

Both above ground and below ground, water storage tanks are used. While below-grade tanks are almost always made of concrete (Figure 11-3), above-grade water tanks (Figure 11-4) may be made of steel, plastic, or concrete.

Figure 11-3: Below-Grade Water Storage Tanks with Exposed Lids

Figure 11-4: Above-Grade Water Storage Tanks (Concrete on Left, Steel on Right)

iv. **Water pumping stations**

Water pumping stations have pumps driven by electric motors to pressurize them, allowing pumping into high-altitude water tanks for distribution by gravity or maintaining pressure to directly distribute water under high pressure though pipes.

Figure 11-5: Water Pumping Station

v. **Water distribution network of metal or plastic pipes**

Piped distribution systems employ underground pipes to transport water from the water treatment plant to consumers. The water is typically treated and chlorinated before distribution. A variety of water pipes of various diameters and materials, such as PVC, cast iron, copper, and steel are used in water distribution systems. Pumping stations are used to raise the pressure to suitable levels to allow water flow through the distribution network of pipes. Pipes are jointed together to make extended runs using different types of joints including flange, nipple, compression, or soldered joints.

Figure 11-6: PVC Pipes for Water Distribution Systems

Water valves are used to control and regulate the flow of water in distribution network.

vi. **Sanitary sewer system**

A sanitary sewer system consists of underground network of pipes or tunnel system constructed to transport sewage and wastewater from homes and commercial buildings to sewage treatment plants for treatment and disposal. Sewer manholes located strategically along the route allow access for inspection of the underground sewers. Sewage typically flows through pipes under gravity, but pressurized mains are also sometimes used. Buried PVC pipes are most common for sewer drains.

Figure 11-7: Sanitary Sewer Manhole

vii. Sewage treatment plants

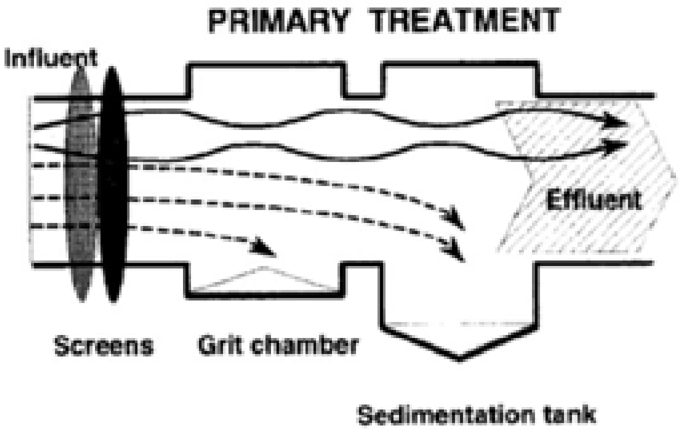
Secondary sewage treatment plants are used to treat sewage trucked from the household septic tanks, before it is discharged. In the Pacific, secondary treatment plants are more commonly used in relation to piped sanitary sewer systems. There are two basic stages in the treatment of sewage waste: primary and secondary treatment.

a. Primary sewage treatment plant

In the primary treatment stage, solids can settle and be removed from wastewater. The secondary stage uses biological processes to further purify wastewater before it is discharged.

Figure 11-8 shows the flow diagram for the primary waste treatment stage.

Figure 11-8: Primary Sewage Treatment Stage Flow Diagram

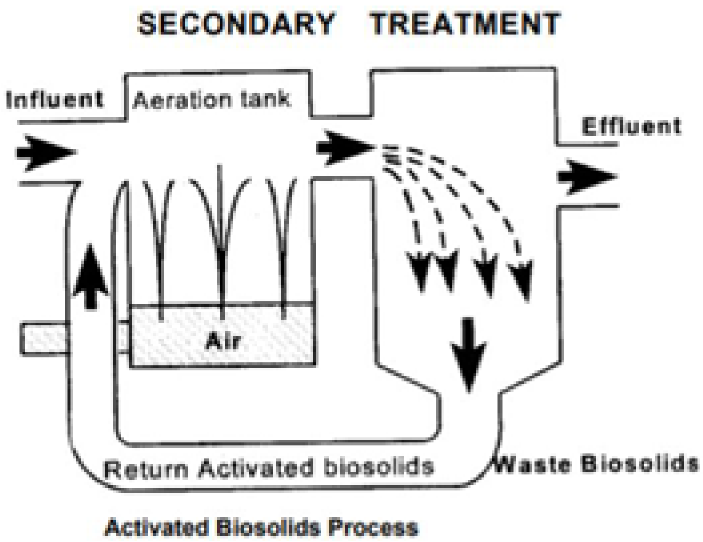


Sewage entering the primary treatment plant flows through a screen to remove large floating objects that might clog pipes or damage equipment. The screened sewage then passes into a grit chamber where heavier objects, such as cinders, sand, and small stones, settle to the bottom. At this stage sewage still contains organic and inorganic matter, along with other suspended solids, in form of minute particles, and these are removed in a sedimentation tank. In the sedimentation tank, the flow speed is reduced, allowing the suspended solids to gradually sink to the bottom as primary biosolids or sludge. Biosolids are usually removed from tanks by pumping, and these biosolids, after further treatment, can be used as fertilizer or disposed of in a landfill.

b. Secondary sewage treatment plant

As seen in the flow diagram in Figure 11-9, after effluent leaves the sedimentation tank in the primary stage it either flows to or is pumped to the secondary treatment facility. The main components used in secondary treatment are the trickling filter and the activated sludge process. A trickling filter is simply a bed of stones from 3 to 6 feet deep through which sewage passes. Modern designs also use interlocking pieces of corrugated plastic or other synthetic media in trickling beds. Bacteria gather and multiply on these stones until they can consume most of the organic matter. The cleaner water trickles out through pipes for further treatment. From a trickling filter, the partially treated sewage flows to another sedimentation tank to remove excess bacteria.

Figure 11-9: Secondary Sewage Treatment Stage Flow Diagram



Some modern designs use activated sludge process instead of trickling filters. After the sewage leaves the settling tank in the primary stage, it is pumped into an aeration tank, where it is mixed with air and sludge loaded with bacteria and allowed to remain for several hours. The activated sludge speeds up the work of the bacteria by bringing air and sludge heavily laden with bacteria into close contact with sewage.

The sludge, activated with additional billions of bacteria and other tiny organisms, is used again by returning it to the aeration tank for mixing with air and new sewage. From the aeration tank, the partially treated sewage flows to another sedimentation tank for removal of excess bacteria. To complete secondary treatment, effluent from the sedimentation tank is usually disinfected with chlorine before being discharged into receiving waters.

The service life of water and sewer infrastructure assets is highly variable, depending on the quality of construction and maintenance. Typical service life for various assets, when maintained in accordance with supplier recommendations, is indicated in Table 11-1.

Table 11-1: Typical Useful Life—Water and Sewer Assets

Water Supply Asset	Asset Type	Typical Useful Life
Water Production plant	Desalination plant	25 years
	Rain harvesting equipment	30 years
Water Distribution System	Pumping equipment	10 years
	Water distribution pipes	50 years
Sewage Infrastructure	Sewer pipes and manholes	50 years
	Sewer treatment plant	25 years

11.2. Typical Degradation Modes

In a rain harvesting system, there are two potential degradation modes. The first impacts the efficiency of water collection and the second the quality and safety of water supply. Over time, gutters can get separated from the roof, resulting in water loss. Downpipe connections to gutter or tanks can become loose, resulting in water leaks. Gutters or downpipes can also get choked with leaves, resulting in overflowing gutters and loss of water. Concrete cisterns can develop cracks, creating water leaks. Plastic storage tanks can be damaged if hit with a heavy sharp object or can be blown over (when empty) under strong winds.

The larger risk with water storage systems is the contamination of water supply. Bacteria of faecal origin can cause diarrhoea and other life-threatening diseases (e.g., typhoid fever). Water collected from raised roof catchments is likely to be better protected against contamination from human faeces. However, wind-blown dust particles, birds, reptiles, and cats can carry human faecal pathogens from the ground level onto roof catchments. Animals can also deposit their own faeces on such surfaces, increasing the risk of contamination. Pathogenic bacteria may be attached to animal or bird droppings falling on the roof. Below-grade water cisterns are more vulnerable to water contamination from seawater or sewage. When toilet pits get flooded during high tides, with seawater rising through coral gravel under soil, water stored in cisterns with cracks can get contaminated. If water entering the tank is not filtered, tree leaves can enter the water tank. Tree leaves and other organic materials provide nutrients for microorganisms, keeping them alive—this can taint the water.

The main operational problem with reverse osmosis units is fouling. Fouling is caused when membrane pores are clogged by salts or suspended particulates. It limits the volume of water that can be treated before cleaning is required. Membrane fouling is corrected by backwashing or cleaning, once about every 4 months. The cartridge filter elements require replacement about every 8 weeks and the membranes have a service life of about 5 years.

In water distribution systems, pipe joints can fail under pressure. PVC pipes can also get damaged from accidental digs. Water pumps are mechanical rotating devices, with bearings and bushings which begin to fail after a useful life of about 10 years or less. The condition of pumps deteriorates with time and the actual age. Intensity of corrosion, quality of coatings and paints, and magnitude of vibrations all indicate a pump's operating condition. Defective pump controls can cause sudden damage to pump operations.

A sewage treatment plant has several components, the performance of which degrades with time. Most tanks are made of steel, which is prone to metal corrosion. If large nonbiodegradable and floating solids are not effectively removed by screens, it may lead to damage and/or unnecessary wear and tear, pipe blockage, or accumulation of unwanted material that interferes with wastewater treatment. When not maintained properly, the screens can get clogged, blocking the flow of effluent from one tank to the next. Bearings and bushings in pumps develop friction with age, eventually leading to pump failure. And if the volume of waste entering the sewage treatment plant exceeds its rating, it would allow less time for bacteria to break down the solid waste and lead to unsatisfactory results.

An improperly functioning treatment plant could mean that total nitrogen targets, phosphorus, or biochemicals targets in the effluent or foul odours (generally related to the presence of hydrogen sulphide) are not met.

Sewage pipes can get blocked, reducing the effective area for sewage flow. Concrete or clay pipes, when used, can also develop cracks. In manholes, concrete spalling may occur or the manholes may get damaged when subjected to vehicular loads in excess of the design rating.

Table 11-2 shows the level of vulnerability of water and sewer structures to typical natural disasters.

Table 11-2: Vulnerability of Coastal Protection to Damage from Natural Disasters

Natural Disaster	Vulnerability to Damage	Asset Components Most at Risk
Earthquake	High - concrete structures low - all remaining assets.	Concrete water storage tanks.
Flooding	High	Water production plant and underground storage tanks.
Windstorm	Low	Rainwater harvesting gutters.

11.3. Physical Condition Assessment Techniques

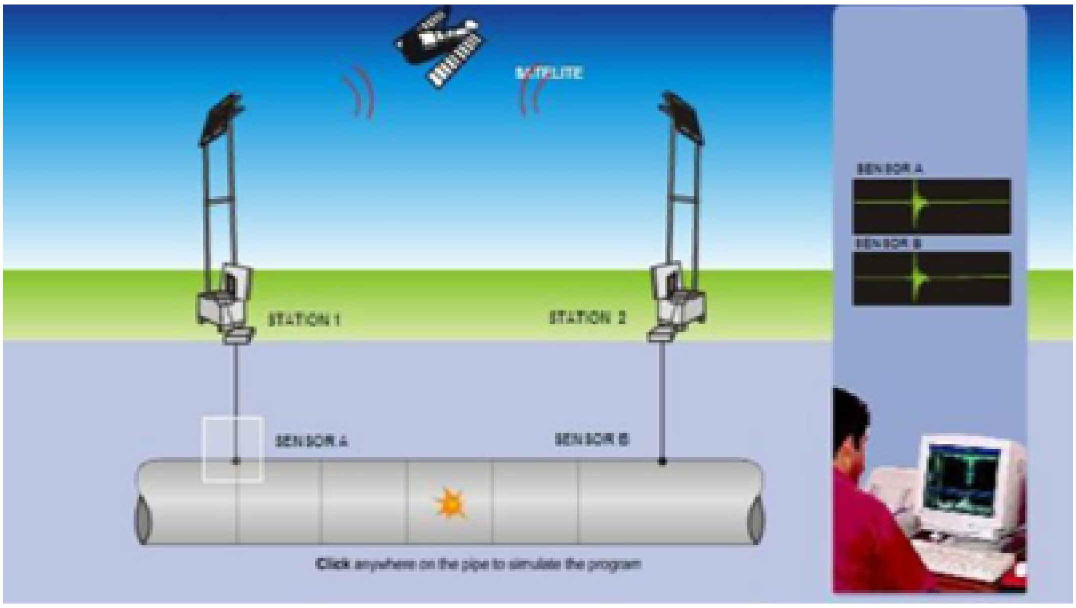
Condition assessment of water production facilities and sewage treatment plants are performed through visual inspection and review of recent plant performance to confirm correct operations and identify the factors that have contributed to operational disruptions. The quality of water produced by freshwater facilities and quality of sewage discharge are verified through lab tests.

For condition assessment of underground water or sewer pipes, a number of technologies allow leak detection, a pipe's structural condition assessment, and hydraulic performance assessment. These technologies include infrared thermal scans and acoustic emission monitoring to identify water leak locations, ultrasonic monitoring, and soil surveys to assess the corrosion of metal pipes, and pressure and flow monitoring to confirm correct operation of water distribution pipes.

Infrared thermal scans are effective in providing heat signature images which may indicate leaks in freshwater or wastewater lines. Acoustic emission monitoring devices can identify occurrence of microscopic cracks in pipes.

Acoustic emission monitoring devices, as shown in Figure 11-10, can identify occurrence of microscopic cracks in pipes.

Figure 11-10: Detection of cracks in water pipes through acoustic emission monitoring



For sewer drains, a CCTV camera (sewer camera) is an extremely effective tool. The small camera can enter any drain or sewer pipe for diagnosing the problem and, through an attachment to a screen with a cord, it brings the live pictures of the pipe's interior to the screen (Figure 11-11). The camera can rotate and navigate through any difficulties, such as roots or tiny objects that may be blocking the pipe.

Figure 11-11: CCTV Camera Inspections of Sewer Pipes

Figure 11-12 shows a steel and a concrete water storage tank in poor condition, due to excessive rust on the steel wall of the tank and a large crack in the wall of the concrete storage tank, both of which pose a serious risk of water leakage.

Figure 11-12: Water Storage Tanks in Poor Condition

Table 11-3 summarizes the common degradation modes and distress symptoms that should be considered when assigning physical condition ratings to water and sewer infrastructure. When the field inspectors are unsure of how to rank the condition of some components, the details of component degradation should be recorded and photographed for referral to a civil engineer.

Table 11-3: Water/Sewer Infrastructure Degradation Modes and Condition Assessment Considerations

Water Supply Asset	Asset Type	Degradation Modes	Distress Symptoms to Consider When Selecting Condition Rating
Water Production plant	Desalination plant	Clogged membranes and cartridge filters leading to fouling, friction in pump bearings and bushings.	Quality of membranes and cartridge filters, operating temperature, noise, vibrations in pumping equipment.
	Rain harvesting equipment	Cracks in storage tanks, detached gutters, blocked gutters, leaking downpipes.	Severity of water leakage from cracked storage tanks, gutters or downpipes, severity of risk of water contamination.
Water Distribution System	Pumping equipment	Friction in pump bearings and bushings, leaking gaskets.	Operating temperature, noise, vibrations in pumping equipment, leakage of water.
	Water distribution pipes	Water leaks.	Severity of water leakage.
Sewage Infrastructure	Sewer pipes and manholes	Cracks in concrete manholes, blockage of pipes.	Extent of blockage to safe and reliable flow of discharge through pipes or extent of damage to manholes.
	Sewer treatment plant	Corrosion of steel tanks and hardware, damage to filters and screens, bushings and bearings increase in friction.	Extent of corrosion on steel members, extent of damage to filters and screens, condition of bearings and bushings in pumps.

11.4. Recommendations for Maintenance

11.4.1. Water desalination plant

Maintenance of water desalination should be carried out strictly in accordance with manufacturer recommendations indicated in the manual. Maintenance activities typically involve:

i. Scheduled inspections and minor maintenance

These include the following activities:

a. replacement of cartridge filter elements once every 2 months;

b. backwashing of the clogged membrane once every 4 months; and

c. instrument calibration and structural repair of the system on a planned schedule per manufacturer's recommendations.

ii. Planned condition assessment

Planned condition assessment should be performed once every 5 years and should include comprehensive condition assessment of the membrane and its replacement.

iii. Reactive maintenance

Reactive maintenance for water desalination plants involves day-to-day monitoring of the system operations, including the following tasks:

a. pump adjustment,

b. chemical feed inspection and adjustment, and

c. leak detection and repair.

11.4.2. Rainwater harvesting system

For rainwater harvesting system, the following maintenance activities are required:

i. Planned minor maintenance

Planned minor maintenance of a rainwater harvesting system should be performed twice a year and include the following steps:

a. clean and clear all gutters of vegetation and leaves;
b. inspect joints in pipes for leaks;
c. re-attach and repair any gutters and downpipes, where rainwater is leaking;
d. clean the coarse filter when a filter is used; and
e. identify damaged/cracked roofs of below-grade water cisterns, through which contaminated ground water could leak into the water cistern, and repair.

ii. Reactive maintenance

Reactive maintenance involves repairs and reattachment of gutters and downpipes whenever leaks are noticed.

iii. Planned major maintenance

Planned major maintenance should be performed annually. The recommended tasks are as follows:

a. The tank be partially drained, leaving about 1,000 liters of water in the tank. About a half bottle (125 milliliters) of plain household grade unscented and uncolored bleach (with 4% active chlorine) should be added to the water. The tank bottom and sides should be thoroughly scrubbed with this solution using a brush. The remaining water and bleach solution should then be drained out of the tank and the tank refilled with water and left to settle overnight before use. Proper hand and eye protection should be worn when handling chlorine bleach solutions.
b. Water quality in tanks should be tested by the Ministry of Health and results compared against World Health Organization water quality guidelines. Testing of water quality can guide when tanks need to be cleaned or disinfected. During water quality tests, the focus should be on microbiological testing using tests such as thermotolerant coliform count, *Escherichia coli* (E. coli) count, or the simple hydrogen sulfide (H2S) test.

iv. Planned condition assessment

Planned condition assessment should be performed once every 5 years and should include comprehensive condition assessment of the water tanks and water storage cisterns.

11.4.3. Sewage treatment plant

i. Scheduled inspections and minor maintenance

This should include the following tasks:

- inspect headwork facilities for proper operations and make repairs if any deficiencies are discovered, including bar screen, static screens, and grit removal;
- inspect and clean waste activated sludge pumps and return activated sludge pumps;
- inspect, clean, and repair motor control panels in wastewater treatment plants;
- perform infrared scans to locate hotspots on electrical equipment;
- inspect effluent ponds or storage tanks for defects or deficiencies;
- test torque alarms if rake and skimmer arms and repair not working, major damage can be caused if something gets tangled in the skimmer arm and torque does not shut down the drive;

- clean and inspect effluent filters;
- if sludge drying beds are utilized, make sure media and under drains are in proper operation;
- inspect sludge transfer pumps for proper operation;
- inspect air release valves for proper operation, if an air release valve is not operating properly, it could lead to a wastewater spill or cause lift station pumps to run longer and use more electricity;
- operate/exercise all valves for proper operation, note any deficiencies, and ensure corrective action;
- groundwater and soil sampling near the sewage treatment facility; and
- measuring the level of obnoxious gases near the sewage treatment facility.

ii. Planned condition assessment

This should be performed once every 5 years and should include comprehensive condition assessment of the treatment plant.

iii. Reactive maintenance

The scope of reactive maintenance and planned major repairs should be based on the results of the condition assessment and recommendations of the subject matter expert.

11.5. Data Collection Requirements to Effectively Manage the Assets

The data collection requirements for asset management functions of water production or sewage treatment plants are summarized in Table 11-4 and for asset management functions of water or sewage pipes in Table 11-5.

Table 11-4: Water Production or Sewer Treatment Plant Data Collection Requirements

Asset Hierarchy	Water or sewer plant ID
	Name of country
	Service sector
	Infrastructure category
	Facility location - GPS coordinates
	Names of districts served by plant
	Number of consumers served by plant
Construction Details	Processing capacity of the water or sewer plant
	Type of technology
	Sub-type of technology
	Name of manufacturer or supplier
Asset Component Condition and remaining Service potential	Physical condition rating of plant
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional performance Rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction
	Unit cost for plant

Table 11-5: Water or Sewer Pipe Data Collection Requirements

Asset Hierarchy	Water or sewer pipelines
	Name of country
	Service sector
	Infrastructure category
	Facility location - GPS coordinates (start section)
	Facility location - GPS coordinates (end section)
	Names of districts served by pipe
	Location of plant to which pipe is connected
	Identification of control valve
	Number of consumers served
Construction Details	Name of manufacturer
	Catalogue number
	Pipe material
	Pipe diameter
	Number of manholes
	Average burial depth
Asset Component Condition and remaining Service potential	Condition of pipe
	Basis for condition rating, if the rating is less than 3
	Condition of manholes
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional performance rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Condition of pipe
	Condition of manholes
	Asset functional performance score
	Annual maintenance cost
	Original cost of construction
	Unit cost for plant

12. Electricity Generation and Distribution Assets

12.1. Main Infrastructure Assets

The main assets employed in electricity generation and distribution systems include:

- diesel generating sets
- solar photo voltaic (PV) generation plant
- overhead distribution lines
- underground cable installations
- medium voltage switchgear
- distribution transformers.

Diesel generators are the main source of power generation in most Pacific countries. Two types of diesel generators are commonly employed: medium speed generators operating at about 900 rpm and high-speed generators operating at about 1,800 rpm. The medium speed generators have higher initial purchase costs and provide a longer service life, and these are used to serve the base load and are running all the time. The high-speed generators have lower purchase cost and significantly shorter service life. Therefore, the high-speed generators are commonly used during peak load periods to supplement the production of base load generators. The medium speed diesel generators are almost always water cooled and employ radiators.

Many Pacific countries have recently invested or are planning to invest in photo-voltaic solar generating plants, which employ sunlight for fuel. Because the sunlight is not available for 24 hours, these solar plants need to be backed up either by storage batteries or diesel generators.

The distribution system receives power from the generating plant and distributes it to consumer premises. Distribution systems may employ either overhead lines or underground cables or a combination of both. Distribution lines employ medium voltage lines typically operating at 11 kilovolts (kV) or 22 kV or 33 kV and low voltage lines, typically operating at 240/415 volts. Overhead lines typically employ wood or concrete poles, aluminum or steel-reinforced aluminum conductors and porcelain or polymer insulators. Underground circuits typically employ cross linked polyethylene insulated cables.

Switchgear is required for switching both medium voltage and low voltage circuits. Modern switchgear consists of either vacuum circuit breakers or SF6 circuit breakers. Switchgear is commonly installed on concrete pads.

Distribution transformers are required to transform medium voltage to low voltage. Distribution transformers are typically insulated with mineral insulating oil. Both pole-mounted and pad mounted distribution transformers are in use in the Pacific.

The typical useful life of electricity generating and distribution assets is indicated in Table 12–1

Table 12-1: Electricity Assets' Typical Useful Life

Electricity Distribution Assets	Asset Type	Typical Useful Life
Diesel Generators	Medium speed	7 years or 60,000 hours*
	High speed	3 years or 25,000 hours*
PV Solar Plant	Fixed or rotating axis	25 years
Distribution Lines	Overhead pole lines	40 years
	Underground cables	40 years
Switchgear	SF6 or vacuum	40 years
Transformers	Pad or pole mounted	40 years

Note: *Can be extended through prime mover overhaul, PV = photo voltaic.

12.2. Typical Degradation Modes

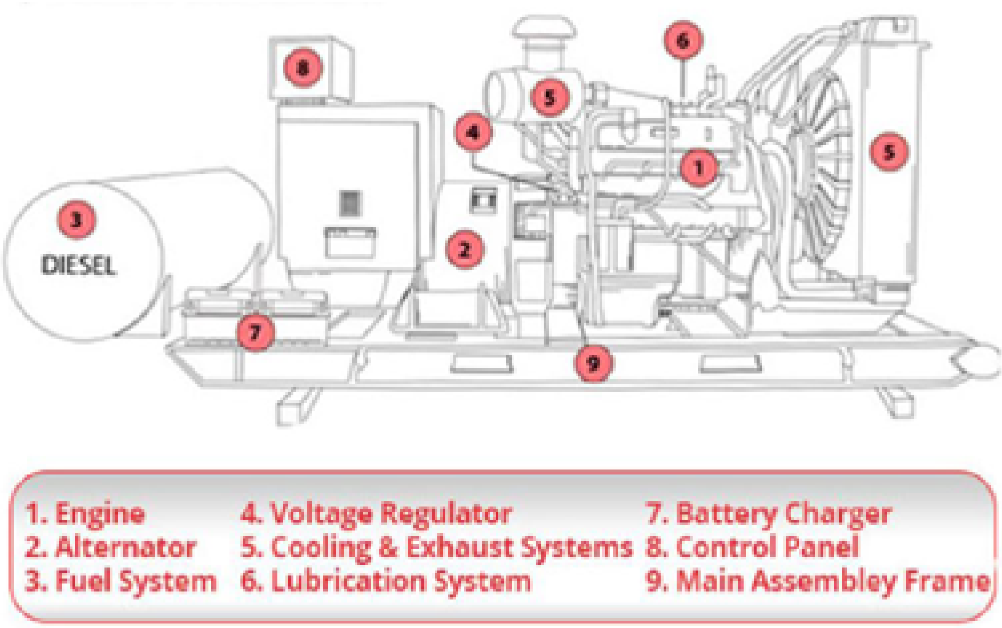
12.2.1. Diesel generators

Diesel generating sets employ reciprocal engines as a prime mover and have a finite service life. Just as in motor vehicle engines, moving parts—including pistons in cylinders, cranks, bearings, etc.—continually wear on service and require periodic maintenance. Engine lubricating oil, engine cooling fluid, fuel filters, oil filters, and air filters become clogged with service and require replacement. Gaskets and O rings develop leaks. Other wearing parts are the seals and bearings that are in constant contact with the rotating shaft.

All steel parts experience corrosion and rusting. Lubricants lose their viscosity under heat and need to be replaced at specified intervals. Water cooled engines also develop sludge in radiators, which reduces their cooling efficiency and when an engine is running at higher temperature, it accelerates degradation. A diesel engine is directly coupled to the electrical generator through the shaft and misaligned couplings can substantially increase the degree of mechanical wear. A generator with higher than normal vibration indicate alignment problems, nonuniform air gaps, bearing damage, loose fastenings, or rotor imbalance.

The electrical windings of rotating electrical machines are subjected to electrical, mechanical, and thermal stresses, all of which result in insulation degradation. The useful service life of electricity generators often depends on the insulation durability. Particular attention should be paid to rotor wear and tear, because even small damages in the rotor can lead to severe damages in the stator, which are extremely expensive to repair. Generators are equipped with an automatic voltage regulator and this device continuously monitors the output voltage and automatically initiates corrective actions to maintain the terminal voltage of the generator constant. The automatic voltage regulator also controls the operation of the synchronous generator within pre-set limits. Any problems with automatic voltage regulator operation can affect the output voltage, resulting in serious power quality problems.

Figure 12 -1: Diesel Generator Components

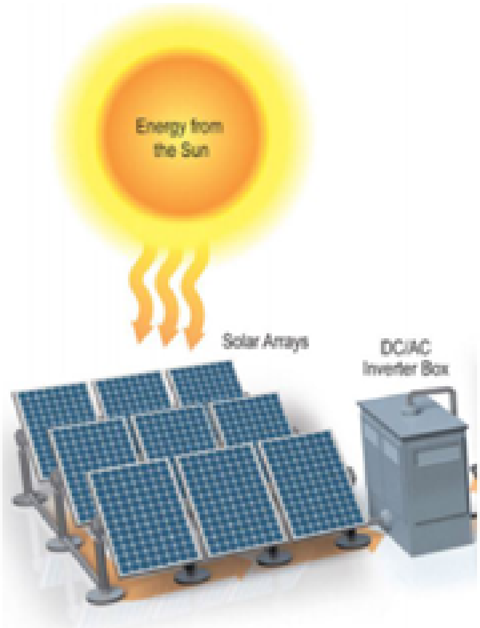


12.2.2. Solar photo voltaic (PV) generating plant

A solar PV plant consists of solar panels mounted on either rooftops or ground mounted structures with hardware. The DC output from the PV panels is changed to AC through an inverter and AC output of the inverter is connected to the grid. When DC storage batteries are employed, output of the panels is connected to the batteries and the output form battery is connected to the inverter.

Solar panels degrade with service and their output begins to decrease significantly after service life of about 20 years. There are different types of storage batteries in use, including sealed lead acid batteries, nickel cadmium batteries, and lithium ion batteries. Battery life is determined by the number of deep charge discharge cycles and can vary from 4 years to about 8 years. Both solar panels and electricity storage batteries contain hazardous materials and require a disposal plan, when these assets reach the end of their service life.

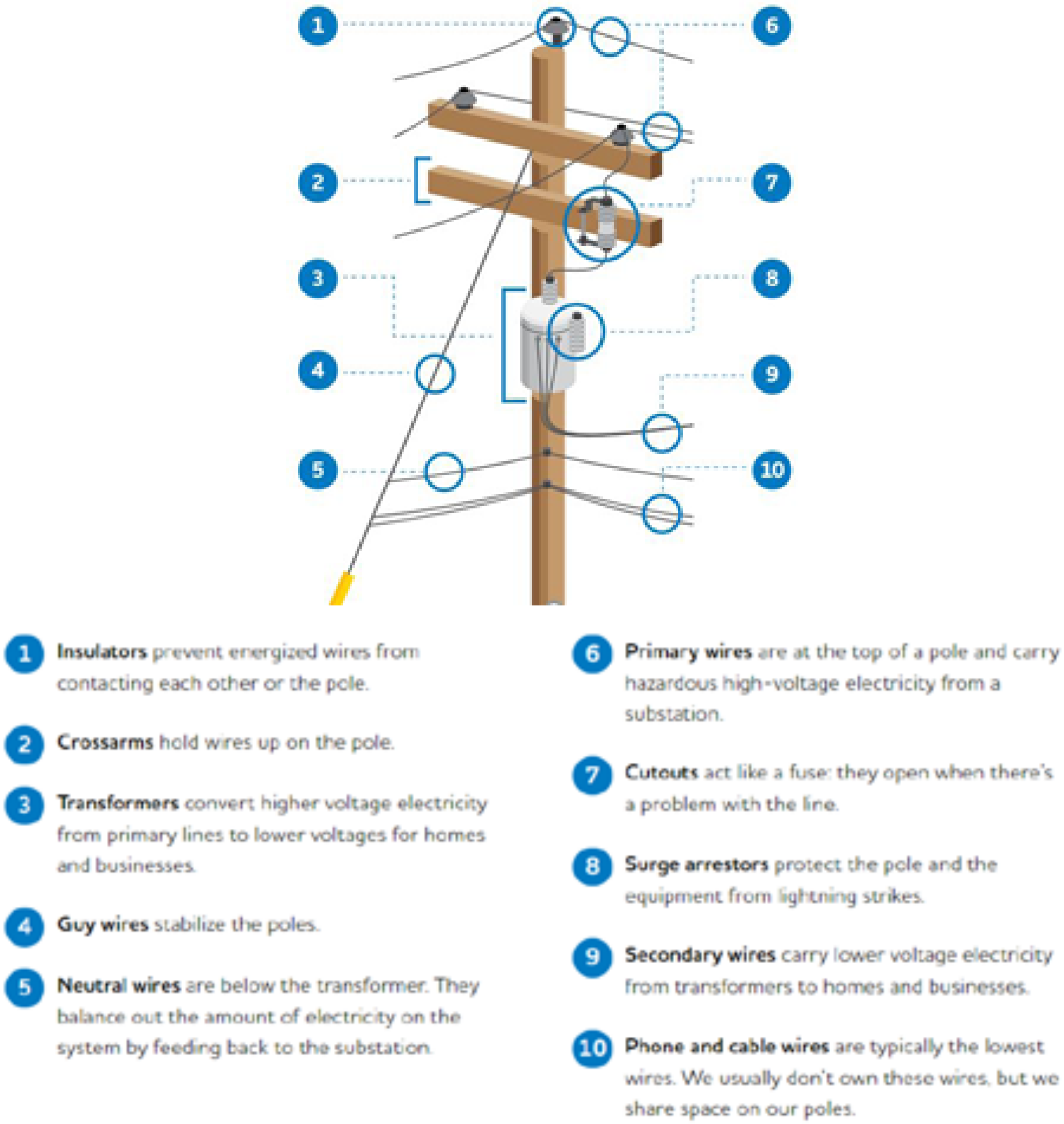
Figure 12-2: Photo Voltaic Solar Components



12.2.3. Overhead distribution lines

Overhead lines consist of structural supports in form of wood, concrete, or steel poles, insulators, conductor, hardware, and many other pieces of equipment installed on lines. Poles provide the support structures for overhead lines to maintain the required clearance between live conductors and grounded objects, for safe and reliable operation of the power supply system. For wood poles, the most critical degradation involves fungal decay of wood or damage caused by wildlife. Wood poles are most susceptible to fungal decay at and around the ground line, where wood can absorb water from the surrounding earth. Pole rot can also begin at the top of the pole. To slow the decay of wood poles, they are commonly treated with preservatives before installation. In addition to wood decay, external damage to poles can be caused by termites or woodpeckers. Deformation of bolt holes can also cause structure failure and the live conductors to fall. In addition, bolts can become loose, elongated, bent, cracked, sheared, or broken. Steel poles degrade due to corrosion, which is more pronounced in Pacific countries due to saltwater spray from the ocean. Concrete poles may degrade due to spalling or accidents with motor vehicles.

Figure 12-3: Typical Overhead Distribution Line Components



Porcelain or polymer insulators are commonly used on overhead lines. Degradation and eventual failure can result from the loss of either dielectric or mechanical strength. Mechanical loading on suspension or post insulators consists of a combination of tensile, torsional, cantilever, vibration and compression forces. Contamination of insulator surface with salt spray from ocean can induce flashovers resulting in dielectric failure of insulators. Typical damage to polymer insulators includes cuts, splits, holes, erosion, tracking, or burning of the rubber shed and sheath material. Electrical flashovers can cause both external and internal damage to porcelain and composite insulators.

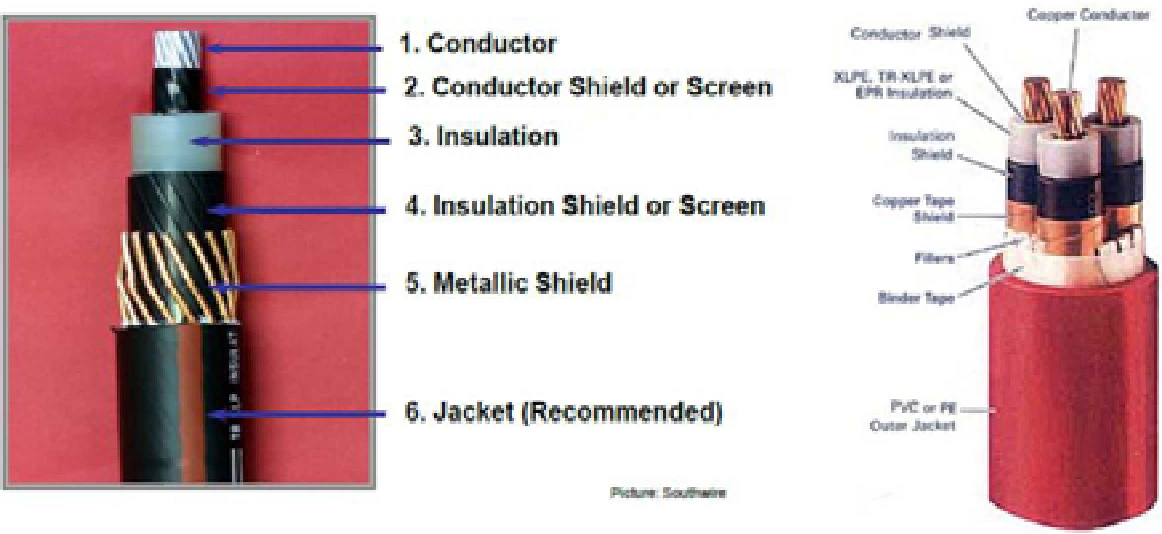
Both aluminium conductor, steel reinforced and all aluminium conductors experience degradation due to corrosion of strands. While steel strands begin to rust more rapidly, aluminium strands are also susceptible to corrosion from salt spray. Overloaded line conductors, operating beyond their thermal capacity, can suffer from a loss of tensile strength due to annealing at elevated operating temperatures. Phase to phase power arcs can result from conductor galloping during severe storm events, resulting in broken strands, strand abrasion, bird caging, or burn damage.

12.2.4. Underground cable circuits

The main degradation mode for cross-linked polyethylene cables is formation of water trees and deterioration of insulation under partial discharge activity. The presence of moisture and impurities in the insulation system accelerate insulation degradation due to water treeing. Corrosion of concentric neutrals is another mode of degradation. Insulation degradation and cable failures can be accelerated if a cable jacket is damaged, allowing moisture to enter the insulation system. Cable degradation can also occur due to overheating under overloading or short circuit conditions. Overstressing of insulation during voltage surges can also lead to cable failures.

Polymeric insulation is very sensitive to partial discharge activity. It is therefore very important that the cables, joints, and accessories are discharged free when installed. Partial discharge testing is, therefore, an important and useful test for these cables. Water treeing is the most significant degradation process for polymeric cables.

Figure 12-4: Typical Distribution Cables



Note: EPR = ethylene propylene rubber, PVC = polyvinyl chloride.
Source: Southwire 25kV, MV, XLP Cables Catalog 2015.

12.2.5. Switchgear

In case of both vacuum circuit breakers and SF6 insulated switchgear, if the integrity of interrupter seals is maintained, the equipment provides reliable, trouble free service for up to 40 years. But if the tanks degrade due to rust and develop pin holes, the insulation system in the current interrupting chamber degrades, causing failure. In the Pacific, the rate of deterioration of steel tanks is very high due to the prevailing corrosive environmental conditions near the ocean; moisture ingress into the insulated unit leads to the end of life for the equipment. Introduction of moisture into the SF6 will result in potential acids forming. The corrosive acids can lead to insulation failure and corrosion of the interior of the switchgear unit. Degradation of the driving mechanism which connects the contacts may also occur. Bearings and linkages can also corrode over time. Degradation of the electrical contacts can also occur after many operations. Surface melting and erosion due to thermal stress, mechanical deterioration due to friction and oxidization of surfaces due to harsh environments can all contribute to equipment failure.

Figure 12-5: Gas Insulated Switchgear

Source: https://new.abb.com/medium-voltage/switchgear/gas-insulated-switchgear

12.2.6. Distribution transformers

Three major factors generally contribute to the degradation of distribution transformers:

- deterioration of the transformer's solid insulation and insulation oil;
- contamination of the bushings (terminals), which can lead to a flashover; and
- rusting and corrosion of the tank, because once the tank has corroded through it can allow the moisture laden air to enter the otherwise sealed tank, thus contaminating the insulation system, which leads to transformer failure.

The most critical component is the internal insulation system, consisting of mineral oil and paper. Transformer oil consists of hydrocarbon compounds that degrade with time due to oxidation, resulting in formation of moisture, organic acids, and sludge. The oil oxidation rate is a function of operating temperature. Increased acidity and moisture content in insulating oil accelerates degradation of the insulation paper. The formation of sludge harms the cooling efficiency of the transformer, raising operating temperatures and increasing the rate of oxidation of both the oil and the paper. Distribution transformers commonly fail when the age-weakened insulation system is subjected to a voltage surge.

If the transformer tanks provide a sealed environment to the interior components, the transformer generally provides a service life ranging from 30 to 50 years, depending on the load level. However, in the corrosive environments along coasts, transformer tanks generally rust through, creating pin holes through welds, allowing the transformer to breathe moisture, which degrades the insulation, causing transformer failure. Exposure to corrosive ocean spray plays a big role in accelerating aging of transformers.

Figure 12-6: Underground and Overhead Distribution Transformers

Table 12-2 shows the level of vulnerability of different electricity assets to natural disasters.

Table 12-2: Vulnerability of Electricity Assets to Damage from Natural Disasters

Natural Disaster	Vulnerability to Damage	Asset Components Most at Risk
Earthquake	Generating plant - high overhead distribution lines - low underground cables - low switchgear - medium transformers - medium.	Concrete pads for equipment foundations.
Flooding	Generating plant - medium overhead distribution lines - low underground cables - low switchgear - medium transformers - medium.	Flooding may interrupt power, but it should not result in permanent damage to equipment.
Windstorm	Generating plant - low, overhead distribution lines - high underground cables - low switchgear - low transformers - low.	Pole lines and pole mounted equipment.

12.3. Physical Condition Assessment Techniques

Condition assessment of water production facilities and sewage treatment plants are performed through visual inspection and review of recent plant performance to confirm correct operations and identify the factors that have contributed to operational disruptions. The quality of water produced by freshwater facilities and quality of sewage discharge are verified through lab tests.

12.3.1. Diesel generating sets

For generators, condition assessment techniques include:

- visual inspections and testing: performed during each scheduled maintenance in accordance with the manufacturer's recommendations to identify deficiencies, including excessive noise, vibrations, operating temperature, extent of corrosion on external components, leaking gaskets, cooling components, and identification of parts requiring replacement;
- infrared thermal scan to identify overheating components;
- monitoring of operating hours since last overhaul;
- monitoring of average demand (kilowatts); and
- monitoring of fuel and oil consumption comparing against benchmarks.

12.3.2. PV solar panels

For PV solar panels, condition assessment techniques include:

- visual inspections and testing: performed during each scheduled maintenance in accordance with the manufacturer's recommendations to identify deficiencies and identification of components requiring replacement, physical damage to panels, extent of corrosion of support structures, contamination of panel surfaces with dirt, leaves or debris;
- infrared thermal scan to identify hot spots; and
- testing to measure panel output.

12.3.3. Overhead distribution lines

For overhead lines, condition assessment techniques include:

- visual inspections: line patrols performed at 3-year intervals to identify deficiencies, including line clearances, hardware corrosion, condition of insulators, condition of support structures, and guys;
- observing below-grade degradation of poles through partial excavation of surrounding soil;
- nondestructive testing of wood poles to identify internal rot;
- structural analysis to determine pole strength, comparing to structural loading under specified winds;
- infrared thermal scan to identify hot spots; and
- checking line loading and load balance among phases.

12.3.4. Underground cable installations

For underground cable installations, condition assessment techniques include:

- insulation testing;
- infrared thermal scan to identify hot spots;
- monitoring partial discharge activity; and
- monitoring number of failures per year per kilometer of installed cable not related to accidental dig-ins.

12.3.5. Medium voltage switchgear

- visual inspections: performed at 5-year intervals to rank the condition of external components, including degree of corrosion, SF6 pressure gauge readings, and condition of bushings;
- insulation resistance measurements with megger and comparing them against new equipment condition;
- contact resistance measurements with micro-ohmmeter;
- infra red scan; and
- monitoring operations counter.

12.3.6. Distribution transformers

For distribution transformers, condition assessment techniques include:

- visual inspections: performed at 3-year intervals to rank the condition of external components, including degree of corrosion, on the transformer tank, oil leaks, and condition of bushings;
- infrared thermal scan to identify hot spots;
- test results of insulating oil;
- monitoring service age; and
- monitoring average loading (kilo-volt-ampere) or operating temperature.

Figure 12-7 shows a concrete pole and a wood pole, in poor condition.

Figure 12-7: Overhead Line Poles in Poor Condition

Table 12-3 summarizes common degradation modes and distress symptoms that should be considered when assigning physical condition ratings to electricity infrastructure. When the field inspectors are unsure of how to rank the condition of some components, the details of component degradation should be recorded and photographed for referral to an electrical engineer.

Table 12-3: Electricity Infrastructure Degradation Modes and Condition Assessment Considerations

Electricity Distribution Assets	Asset Type	Degradation Modes	Distress Symptoms to Consider When Selecting Condition Rating
Diesel Generators	Medium or high speed generators	Excessive noise, vibrations, hot spots, corrosion of steel members, worn out bushings/bearings, increased fuel consumption, leaking radiators.	Noise level, vibration level, extent of hot spots, extent of corrosion, condition of bushings and beatings, fuel consumption, extent of water leaks in radiators.
PV Solar Plant	Fixed or rotating axis	Corrosion of steel hardware, damaged/ defective panels, defective inverter, degraded insulation, hotspots.	Degree of corrosion, extent of damaged/ defective panels and inverter, cable insulation condition, extent of hotspots.
Distribution Lines	Overhead pole lines	Decayed wood poles, rusted steel poles and hardware, cracks in concrete poles, partial discharge (PD) activity, appearance of hotspots.	Extent of degradation of support poles and crossarms, extent of hardware corrosion, degree of PD activity, extent of hotspots.
	Underground cables	Insulation degradation, hot spots, partial discharge activity.	Pooot insulation test results, extent of hotspots and PD activity, number of cable failures.
Switchgear	SF6 or vacuum	Leaks in vacuum or SF6 bottle, low insulation resistance, high contact resistance (IR), partial discharge (PD) activity, hot spots.	Integrity of vacuum or SF6 bottle, IR measurements, extent of PDF activity, extent of hotspots.
Transformers	Pad or pole mounted	Steel tank corrosion, oil leaks, poor quality of bushings, partial discharge activity, hotspots, low insulation resistance.	Extent of corrosion, extent of oil leaks, extent of PD activity, extent of hotspots, poor insulation of oil test results.

Note: PD = partial discharge.

12.4. Recommendations for Maintenance

12.4.1. Diesel generating sets

Electricity generating sets are an extremely expensive and maintenance-intensive asset. Without required maintenance, their service life is significantly reduced. Therefore, electricity generators require scheduled maintenance, strictly in accordance with the manufacturer's recommendations.

i. Scheduled inspections

Routine maintenance and inspection of generating plant are performed daily and include:

- checking lubricating oil levels and leaks,
- checking coolant levels and leaks,
- inspecting exhaust pipes,
- inspecting fuel lines, and
- inspecting control batteries and testing voltages.

ii. Scheduled minor maintenance

Planned minor maintenance activities involves change of oil and oil filters, change of air filters, change of fuel filters, and change of coolant. The minor maintenance activities include:

- tasks recommended to be performed by vendor once every 600 hours for medium speed engines, i.e., change of oil and oil filters and air filters;
- tasks recommended to be performed by vendor once every 6,000 hours for medium speed engines, i.e., change of air fuel filters and coolant.

iii. **Planned condition assessment and major maintenance**

Planned major maintenance activities involve engine overhaul, required after about 60,000 operating hours, in case of medium speed engines.

High speed generators, due to their higher operating speed, experience greater wear of the moving parts and require maintenance even more often, as specified in the manual.

12.4.2. Solar photo voltaic generation plant

Because there are many types of solar panels, inverters, and batteries in use, the maintenance for these solar PV plants should be performed strictly in accordance with the manufacturer's recommendations indicated in the owners operating manual. The following recommendations for maintenance represent general guidelines:

Solar panels and inverters are considered generally maintenance free for the service life of 20 years and do not require any maintenance except for planned minor maintenance.

i. **Scheduled routine inspections and minor maintenance (performed at 3-month intervals):**

The following maintenance activities should be performed once every 3 months:

a. Wash panels with water to remove dust, dirt, and bird droppings. Panels can be rubbed with a soft sponge to remove bird droppings if required, but no hard brushes or chemicals should be used for cleaning.
b. Inspection of the panel wiring to make sure the connections are tight and wires are properly secured.
c. The panel output power should be monitored.
d. For storage batteries, the electrolyte level should be checked and topped when required.

ii. **Planned detailed inspections and maintenance (once a year)**

a. Visually inspect panels and check for defects in the modules such as cracks, chips, delamination, fogged glazing, water leaks and discoloration. If any defects are found, note their location in the system logbook so they can be monitored for further deterioration that affects the modules' output.
b. Inspect solar panel mounting frames for damage or rusting and repaint surfaces when required.
c. Inspect the inverter and remove any dust accumulation with a dry cloth. Inspect to confirm that all the indicators, such as LED lights, are working and that the wires leading to and from this device are not loose. Note that the charge controller should indicate that the system is charging when the sun is up.
d. Check the wiring and conduits to confirm they are free from damage.

12.4.3. Overhead distribution lines

The following are the defects to look out for during three-year interval scheduled detailed inspections and minor maintenance of overhead distribution lines:

a. Detailed inspections of poles with the intent to identify the following common deficiencies:
    - out of plumb, cracked, or broken poles
    - excessive surface wear or scaling on steel poles
    - loose, cracked or broken cross arms and brackets
    - woodpecker or insect damage, bird nests
    - loose or unattached guy wires or stubs
    - guy strain insulators pulled apart or broken
    - guy guards out of position or missing
    - grading changes, or washouts
    - indications of burning.

b. Detailed inspections of pole mounted distribution transformers with the intent to identify the following common deficiencies:

- degree of transformer tank corrosion/rust and the need for repaint
- phase indicators and unit numbers match operating map (where used)
- oil leaks
- flashed or cracked insulators
- contamination/discolouration of bushings
- ground lead attachments
- damaged disconnect switches or lightning arresters
- ground wire on arresters unattached.

c. Detailed inspections of pole mounted disconnect switches with the intent to identify the following common deficiencies:

- Bent, broken bushings and cut-outs
- Damaged lighting arresters
- Ground wire on arresters unattached.

d. Detailed inspections of pole hardware to identify the following common deficiencies:

- loose, rusted, or missing hardware
- insulators unattached from pins
- conductor unattached from insulators
- insulators flashed over or obviously contaminated (difficult to see)
- tie wires unravelled
- ground wire broken or removed
- ground wire guards removed or broken.

e. Detailed inspections of pole mounted cables and conductors to identify the following common deficiencies:

- low conductor clearance
- broken/frayed conductors or tie wires
- exposed broken ground conductors
- broken strands, bird caging, and excessive or inadequate sag
- insulation fraying on secondary.

f. Detailed inspections of vegetation growth near the lines with the intent to identify the following common deficiencies:

- leaning or broken "danger" trees
- growth into line of "climbing" trees
- accessibility compromised
- vines or brush growth interference (line clearance)
- bird or animal nests.

12.4.4. Underground cable installations

Medium voltage or low voltage cables require no maintenance, other than replacement of cable upon failure. Some electric utilities conduct on-site tests to verify the remaining life of cables, but no reliable tests are available at this time, which could be performed cost effectively on distribution cables.

For condition assessment of the cables, the following tasks are required;

(i) For all medium voltage and low voltage circuits, keep records of cable failures, indicating the type of failure, location of failure and cause of failure.

(ii) Plan to replace the cables when the number of repeated failures on a circuit becomes excessively large.

12.4.5. Medium voltage switchgear

Modern distribution switchgear consisting of SF6 or vacuum circuit breakers are sealed inside the tank. If SF6 pressure gauge indicates correct pressure and vacuum bottles are sealed, no maintenance is required. In case of an internal failure, the defective equipment must be replaced with a spare unit. Maintenance activities for switchgear include:

i. Reactive maintenance—site specific repairs of external parts or replacement of the faulty unit with a spare one to meet immediate needs.

ii. Planned minor maintenance—performed once a year—involves completion of the following tasks:

- perform visual inspection to confirm safe condition of power equipment;
- clear the equipment from dirt or debris, if required;
- trim shrubs near the equipment;
- paint rusted surfaces to avoid more serious damage to equipment; and
- perform infrared thermal scan and partial discharge monitoring to detect hot spots or partial discharge activity in insulation systems.

iii. Planned condition assessment of equipment

Condition assessment of switchgear should be performed once every 5 years and includes the following tests:

- operating tests to confirm correct operations for breaker opening under faults,
- partial discharge and infrared thermal scans,
- insulation resistance measurements with megger and contact resistance measurements,
- inspecting for seals and gaskets of SF6 tanks, and
- checking gas pressure and identifying sources of leak.

iv. Planned replacement

There are no major repairs recommended for switchgear; when the condition assessment results indicate poor or very condition, the equipment will need to be replaced.

12.4.6. Distribution transformers

All active electrical components in a distribution transformer are sealed inside the tank. In case of transformers, if the corrosion has not resulted in an oil leak from the tank through welds or gaskets, the transformer does not require any maintenance of internal parts. In most Pacific countries, no maintenance facilities are available to repair internal components of the transformers and in case of an internal failure, the defective equipment must be replaced with a spare unit.

Maintenance activities for distribution transformers include:

i. **Reactive maintenance—site specific repairs of external parts or replacement of the faulty unit with a spare one to meet immediate needs.**

ii. **Planned minor maintenance—performed once a year—involves completion of the following tasks:**
- performing visual inspection to confirm safe condition of power equipment,
- performing infrared scans and partial discharge monitoring,
- clearing the equipment from dirt or debris, if required
- trimming shrubs near the equipment, and
- painting rusted surfaces, to avoid more serious damage to equipment.

iii. **Planned condition assessment of equipment—performed once every 5 years—condition assessment of the transformer should include:**
- testing of oil samples to assess condition of internal insulation,
- measuring insulation resistance with a megger, and
- checking turns ratio to detect shorted coils.

iv. **Planned replacement—there are no major repairs recommended for transformers. When the condition assessment results indicate poor or very poor condition, the equipment will need to be replaced.**

12.5. Data Collection Requirements to Effectively Manage the Assets

The data collection requirements for asset management functions of electricity generating and distribution assets are summarized in Tables 12-4 to 12-9.

Table 12-4: Electricity Diesel Generating Plant Data Collection Requirements

Asset Hierarchy	Electricity diesel generator ID
	Name of country
	Service sector
	Generator type
	Facility location - GPS coordinates
	Names of districts served by plant
	Number of consumers served by plant
Construction Details	Generator rating (voltage, kilowatt)
	Type of technology (medium speed, high speed, diesel or gasoline)
	Name of manufacturer or supplier
Asset Component Condition and remaining Service potential	Physical condition of prime mover
	Basis for condition rating, if the rating is less than 3
	Physical condition of alternator
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional performance Rating, if the rating is less than 3

Table 12-4: Electricity Diesel Generating Plant Data Collection Requirements (continued)

Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction
	Unit cost for plant

Table 12-5: Electricity Solar Power Plant Data Collection Requirements

Asset Hierarchy	PV solar plant ID
	Name of country
	Service sector
	Facility location - GPS coordinates
	Names of districts served by plant
	Number of consumers served by plant
Construction Details	Solar array's DC rating
	Inverter's AC rating
	Solar panel manufacturer name
	Inverter's manufacturer name
	Type of technology
	Sub-type of technology
Asset Component Condition and remaining Service potential	Physical condition of solar array
	Basis for condition rating, if the rating is less than 3
	Physical condition of inverter
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional performance rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction
	Unit cost for plant

Table 12-6: Electricity Overhead Distribution Line Data Collection Requirements

Asset Hierarchy	Overhead distribution line ID
	Name of country
	Service sector
	Infrastructure category
	Facility location - GPS coordinates (start section)
	Facility location - GPS coordinates (end section)
	Names of districts served by the line
	Location of substation from which line is supplied
	Identification of controlling circuit breaker
	Number of consumers served from the line
Construction Details	Length of line section
	Number of poles
	Ruling span length
	Type of poles
	Number of MV circuits
	Line voltage of circuit 1
	Line voltage of circuit 2
	Type and size of conductors on circuit 1
	Type and size of conductors on circuit 2
	Type and size of LV conductors
Asset Component Condition and remaining Service potential	Condition of poles
	Basis for condition rating, if the rating is less than 3
	Condition of conductors and insulators
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional performance rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction
	Unit cost of construction

Table 12-7: Electricity Underground Cable Data Collection Requirements

Asset Hierarchy	Underground distribution circuit ID
	Name of country
	Service sector
	Infrastructure category
	Facility location - GPS coordinates (start section)
	Facility location - GPS coordinates (end section)
	Names of districts served by the circuit
	Location of substation from which circuit is supplied
	Identification of controlling circuit breaker
	Number of consumers served from the circuit
Construction Details	Length of underground cable section
	Number of splices in the cable section
	Operating voltage
	Type of cable configuration
	Name of cable manufacturer
	Type and size of conductors
	Type of cable insulation
	Type of cable jacket
	Type of cable armour
Asset Component Condition and remaining Service potential	Condition of underground cable
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction
	Unit cost of construction

Table 12-8: Electricity Switchgear Data Collection Requirements

Asset Hierarchy	Switchgear ID
	Name of country
	Service sector
	Facility location - GPS coordinates
	Names of districts supplied from the switchgear
	Number of consumers supplied from the switchgear
Construction Details	Switchgear voltage rating
	Switchgear continous current rating
	Switchgear short circuit interrupting rating
	Switchgear manufacturer name
	Type of circuit breaker technology
	Sub-type of circuit breaker technology
Asset Component Condition and remaining Service potential	Physical condition of switchgear
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction

Table 12-9: Electricity Distribution Transformer Data Collection Requirements

Asset Hierarchy	Distribution transformer ID
	Name of country
	Service sector
	Facility location - GPS coordinates
	Names of districts supplied from the transformer
	Number of consumers supplied from the transformer
Construction Details	Name of manufacturer
	Transformer primary voltage rating
	Transformer secondary voltage rating
	Transformer kVA rating
	Single phase or three phase
	Pole mounted or pad mounted
Asset Component Condition and remaining Service potential	Physical condition of transformer
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction

13. Telecom Assets—Condition Assessment

13.1. Main Infrastructure Assets and their Components

The main infrastructure assets employed on telecommunication systems in the Pacific can be divided into the following categories:

i. Telecom towers,

ii. Telecom cables,

iii. Telecom indoor units, and

iv. Telecom outdoor units.

Telecom towers are commonly employed for mounting of outdoor units, including satellite dishes and antennas. Two types of telecom towers are commonly used: self-supporting structures and guyed towers. Both are typically constructed as steel lattice structures varying in height from 10 meters to 40 meters.

Telecom cables are employed for providing wired landline telephone service as well as internet and television cable services. The telecom cables, in the past, consisted of coaxial or multipair twisted pair copper cables, but now fiber-optic cables are almost exclusively used due to their significant benefits over copper cables. Telecom cables installed in the Pacific may be submarine cables for ocean crossings or conventional cables for installation on poles or for underground installations.

Telecommunication's indoor units include solid state devices installed inside climate-controlled rooms, including transistors, capacitors, microprocessors, etc. Telecom outdoor units consist of transmitting and receiving devices; these include antennas and satellite dishes installed on high towers and masts.

Technical obsolescence is often the main reason telecommunication devices reach the end of their service life. Due to fast changing technology, data processing speed, and the need for speed and bandwidth is continually increasing; as a result, most telecommunication products and devices become obsolete within about 10 years.

Table 13-1 shows the typical useful life of different types of telecom assets.

Table 13-1: Typical Useful Life of Telecom Components

Telecom Assets	Asset Type	Typical Useful Life
Towers	Self supporting	30 years
	Guyed	30 years
Fiber Optic Cables	Submarine cables	30 years
	Polemounted cables	30 years
	Underground cables	30 years
Copper Cables	Submarine cables	30 years
	Polemounted cables	30 years
	Underground cables	30 years
Indoor Mounted Units		10 years
Outoor Mounted Units		10 years

Source: Author created

13.2. Typical Degradation Modes

13.2.1. Telecom towers

Telecom towers are typically manufactured from steel, which is susceptible to corrosion. Corrosion rates are particularly high for towers mounted in coastal areas, where they are continually subjected to salt laden water spray. Protective coatings in the form of galvanized steel (with zinc coatings) or painted steel are used, which slow corrosion but cannot eliminate it. Corrosion results in reduction in the cross-section area of steel members, which lower the structural strength of the tower and can eventually lead to its collapse when subjected to strong winds. All towers are designed to withstand a specific wind speed and if the design wind speed is exceeded it may topple the tower.

Figure 13-1: Telecom Towers

13.2.2. Telecom cables

When properly designed and constructed, telecom cables should provide a very long service life. For copper cables degradation modes involve insulation failure when subjected to over-voltages, during lightning surges, or conductor failure when subjected to a short circuit. Cables may degrade when exposed to ultraviolet light. Accidental dig-ins may also lead to cable failure.

Figure 13-2: Twisted Pair, Coaxial, and Fiber-Optic Telecom Cables

13.2.3. Telecom equipment (indoor units and outdoor units)

Communication system hardware is made of solid-state components, the operating characteristics of which undergo change over time. It is difficult to see such small-scale change, because there are no moving parts. However, all the components, including transistors, capacitors, microprocessors, etc. that make up the solid-state devices used in telecommunication systems do undergo change and eventually lose their performance tolerances. When many of these components start operating at less than specified performance, the overall system or device no longer performs as required and the end of life for that device is reached.

A large percentage of communication hardware devices commonly fail either during or just after installation and commissioning. These failures can result from manufacturing defects, commonly referred to as "birth defects", when the manufacturing testing process fails to identify a manufacturing error or substandard component. However, the leading cause of near-term failures is the result of improper installation or operation. Installation failures are commonly caused when technicians fail to familiarize themselves with the manufacturer's recommendations. Sometimes the installation technicians try to use shortcuts to reduce the installation time or because they have installed similar equipment and believe that there are no differences between devices manufactured by different companies. Another common error is to assume that there will not be differences between old and new versions of the same device.

On a long-term basis, most failures are the result of electronic component aging, through cyclical heating and cooling, because of which component performance degrades, and they fail to meet original specifications. Systems will either fail or develop substandard functional characteristics. Telecommunications equipment is also sensitive to over-voltages and can fail when subjected to lightning strikes, switching power surges, and connection of electrical power to a communications port. The reliability of solid-state electronic components is often measured in terms of mean-time-between-failures. As solid-state devices age, mean-time-between-failures starts decreasing and eventually reaches a level below acceptable performance.

Technical obsolescence is often the main reason telecommunication devices reach the end of their service life. Due to fast-changing technology, data processing speed and the need for speed and bandwidth is continually increasing; as a result, most telecommunication products and devices become obsolete within about 10 years.

Table 13-2 shows the level of vulnerability of different telecom assets to damage during natural disasters.

Table 13-2: Vulnerability of Telecom Assets to Damage from Natural Disasters

Natural Disaster	Vulnerability to Damage	Asset Components Most at Risk
Earthquake	Towers - low Submarine cables - low Underground cables - low Pole mounted cables - low Indoor mounted units and outdoor mounted units - low	Concrete pads of towers
Flooding	Towers - low Submarine cables - low Underground cables - low Pole mounted cables - low Indoor mounted units and outdoor mounted units - low	Flooding may interrupt communications, but it should not result in permanent damage to equipment
Windstorm	Towers - high Submarine cables - low Underground cables - low Pole mounted cables - high Indoor mounted units and outdoor mounted units - low	Towers and poles

13.3. Physical Condition Assessment Techniques

13.3.1. Telecom towers

For telecom towers, condition assessment techniques include:

- visual inspections: performed at 3-year intervals for guyed towers and at 5-year intervals for self-supporting towers[15] to identify deficiencies, hardware corrosion, condition of support structures and guys;
- observing degradation of concrete foundations, when used; and
- structural analysis to determine tower strength and comparing to the structural loading under specified winds.

13.3.2. Telecom equipment, including cables:

For telecommunication systems, commonly employed condition assessment techniques include:

Monitoring the rate of component and equipment failure over the recent past. Failure rates in the electronic component industry are commonly measured and monitored in terms of mean time between failures (mean-time-between-failures). Mean-time-between-failures is measured in units of time, i.e., hours or minutes and is calculated as follows.

$$MTBF\ (in\ hours) = \frac{Total\ number\ of\ hours\ in\ a\ year}{Number\ of\ equipment\ failures\ in\ a\ year}$$

Let us assume you have 20 equipment failures on your telecommunication network during the past year. Mean-time-between-failures can be calculated as:

$$MTBF\ (in\ hours) = \frac{8760}{20} = 438$$

A low mean-time-between-failures indicates poor condition of equipment.

Because technical obsolescence is often the main reason telecommunication devices reach the end of their service life, telecommunication assets' condition assessment also includes checking and confirming to what degree the existing technology is meeting customer needs.

Table 13-3 summarizes the common degradation modes and distress symptoms that should be considered when assigning physical condition ratings to telecom infrastructure. When the field inspectors are unsure of how to rank condition of some components, the details of component degradation should be recorded and photographed for referral to a Telecommunications Engineer.

[15] Please see ANSI/TIA Standard 222.

Table 13-3: Telecom Infrastructure Degradation Modes and Condition Assessment Considerations

Telecom Assets	Asset Type	Degradation Modes	Distress Symptoms to Consider When Selecting Condition Rating
Towers	Self supporting or guyed	Corrosion of steel towers and guys wires, Cracks or spalling in concrete foundations.	Extent of corrosion of steel structures and guy wires and extent of damage to concrete foundations.
Cables	Copper or fiber optic	Cable failures.	Mean time between failures.
Indoor Mounted Units or Outdoor Mounted Units	Indoor mounted units or outdoor mounted units	Component failures.	Mean time between failures.

13.4. Recommendations for Maintenance

Initial generations of "state-of-the-art" solid state components and devices required significant adjustments by operations and maintenance personnel. The early vintage solid-state telecommunications equipment was manufactured with external controls to allow adjustments (recalibration) to move the device back to specified parameters. Modern equipment is less affected by its environment, and most manufacturers have eliminated the external adjustment controls. The use of fixed value components minimizes the need for adjustments.

Under the current design, communication devices either perform as specified, or they must be replaced. Manufacturers have created "board level" systems with all necessary components required for a device placed on digital cards, commonly referred to as printed circuit boards.

Most communication system component hardware is constructed on a single printed circuit board that can easily be replaced by a qualified technician. The components are so small that they cannot be repaired or replaced in the field. Simply replacing the board with the failed component saves time and money.

Most communications equipment is built with internal monitoring capabilities. Diagnostics are displayed in one of two general ways: external display on the equipment, or via diagnostics terminal (or as a program on a PC). Most modems have LED indicator lamps to show that the device is functioning in the proper manner. A multiplexer or router will provide diagnostics via a directly connected terminal or through a device setup and management program on a PC.

Telecommunications devices, therefore, require the following types of maintenance activities:

i. Reactive maintenance—which involves reactive maintenance to replace defective components and devices, which is done by replacing digital circuit boards. It is also important to maintain a record in form of log book of all maintenance activities, device failures and replacement of defective cards in a data base. Failure of climate control systems also require immediately replacement. In the field, damaged cables should be replaced immediately.

ii. Planned minor maintenance is recommended to be performed once a year and it should include the following activities:

   a. This task involves field verification in form of inventory taking to confirm the installed equipment against a database.

   b. All equipment mounted outdoors is subjected to corrosion of the connectors. Therefore, the connectors should be inspected for corrosion and cleaned, when required.

   c. Telecom towers may need to be repainted in the field.

iii. Planned condition assessment should be performed once every 5 years—and it should include comprehensive condition assessment of the existing system capability against the current needs to see if the system should be replaced with the next generation of telecommunication devices. Failure rates (mean-time-between-failures) should also be reviewed to assess if mean-time-between-failures for existing system devices is still within acceptable levels.

iv. Asset upgrades—to replace equipment when it has reached "poor" or "very poor" condition.

13.5. Data Collection Requirements to Effectively Manage the Assets

The data collection requirements for asset management functions of telecom plants are summarized in Table 13-4 to Table 13-6.

Table 13-4: Telecom Towers Data Collection Requirements

Asset Hierarchy	Telecom tower ID
	Name of country
	Service sector
	Tower type (guyed or unguyed)
	Facility location - GPS coordinates
	Names of districts served by plant
	Number of consumers served by plant
Construction Details	Height of tower
	Construction material (steel, timber, concrete)
	Type of construction (lattice or tubular)
	Name of manufacturer or supplier
Asset Component Condition and remaining Service potential	Physical condition
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction
	Unit cost for plant

Table 13-5: Telecom Cable Data Collection Requirements

Asset Hierarchy	Cable ID
	Name of country
	Service sector
	Facility location - GPS coordinates start section
	Facility location - GPS coordinates end section
	Names of districts served by plant
	Number of consumers served by plant
Construction Details	Length of cable section
	Type of installation (overhead, underground, submarine)
	Type of cable (copper or fiber-optic)
	Sub-type of technology (coaxial or twisted pair)
	Number of pairs/strands
	Name of manufacturer
Asset Component Condition and remaining Service potential	Physical condition of cable
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction
	Unit cost for plant

Table 13-6: Telecom Indoor and Outdoor Unit Data Collection Requirements

Asset Hierarchy	Telecom indoor unit or outdoor unit
	Name of country
	Service sector
	Facility location - GPS coordinates
	Names of districts served from the equipment
	Number of consumers served from the equipment
Construction Details	Indoor unit or outdoor unit
	Type of Indoor unit or outdoor unit
	Sub-type of indoor unit or outdoor unit
	Manufacturer name
	Type of technology
	Sub-type of technology
Asset Component Condition and remaining Service potential	Physical condition of indoor unit or outdoor unit
	Basis for condition rating, if the rating is less than 3
	Asset functional performance score
	Basis for functional rating, if the rating is less than 3
Asset Replacement and Renewal Cost	Year of construction
	Original cost of construction
	Current replacement cost
	Annual maintenance cost
	Original cost of construction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