JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Comprehensive Industrial Best Practice for Steel Structure Inspection

Aziz Hamid Farooqi

Independent Professional Civil Structural Engineer,

SME, Reg.PE | PMP® | M. ASCE | M.SEI | M.ICE | ACI-SAC

Abstract: Steel structures play a vital role in industrial facilities, necessitating routine inspections to maintain safety, reliability, and adherence to regulatory standards. This document offers a comprehensive examination of best practices for inspecting steel structures within industrial settings, emphasizing the responsibilities of various stakeholders, inspection techniques, detailed methodologies, and specific requirements. It delineates the roles of inspectors, engineers, and maintenance personnel to foster a systematic inspection framework. The guide discusses multiple inspection techniques, such as visual assessments, non-destructive testing (NDT), and corrosion evaluations, providing thorough procedures for detecting structural issues. Furthermore, it underscores essential requirements, including safety measures, environmental factors, and documentation protocols. This resource aims to support industry professionals in refining inspection practices, improving structural integrity, and ensuring sustained operational reliability.

Keywords **–Procedures, non-destructive testing (NDT), corrosion, structural integrity, maintenance strategies, environmental considerations, structural performance, compliance standards, responsibilities**

1. Introduction

In Large Industries such as Refineries, chemical plants, and other substantial industrial operations consist of numerous individual assets, including fixed equipment such as pressure vessels and piping, rotating machinery, and instrumentation and control systems, among others. These assets are supported by a sophisticated network of steel structures, frames, racks, and various other structures, collectively referred to as Steel Structural equipment.

Like all equipment within process facilities, steel structural components experience deterioration over time. Factors such as design flaws, construction issues, severe environmental conditions, degrading circumstances, and alterations in applied loads can result in unexpected failures and operational disruptions. Therefore, it is essential for facilities to implement a thorough structural integrity program that encompasses the design, inspection, maintenance, evaluation, and repair of structural equipment.

Steel structures are integral to industrial operations, providing strength, durability, and adaptability for various applications. However, these structures are not immune to deterioration over time, with corrosion being the primary cause of degradation. Maintenance of steel structures often involves repairing or replacing damaged or corroded components and applying protective coatings to mitigate corrosion risks. Physical damage resulting from impacts or excessive loading also contributes to structural issues, though it is less frequent compared to corrosion.

A robust inspection process is critical for identifying potential issues early, ensuring structural integrity, and prolonging the lifespan of steel structures. This paper explores industrial best practices for steel structure inspection, emphasizing the responsibilities of inspection teams, comprehensive inspection methods, detailed procedures, and special requirements. By adopting these practices, industries can effectively address the challenges associated with structural degradation and maintain compliance with safety and performance standards.

2. PURPOSE AND SCOPE

This paper forms an integral part of steel structure inspection standard compliance with industrial requirements and describes the processes for inspecting steel structures in mainly, plants Chemical Complex. This Steel Structure Inspection Procedure can applies to all steel structures in plant Complex and provides guidance for the processes for undertaking the Visual inspection.

The systematic inspection of structures forms the basis of good asset management practice. The outcomes from the inspection process are used to: -

- Provide the assessment on the current condition, performance and environment of structure including the severity and extent of defects. The assessment report enables those responsible for managing structures in chemical complex to assess if a structure is currently safe for use and fit for purpose.
- Provide assessments where there is a change in condition, cause of deterioration, maintenance requirements and effectiveness of maintenance.
- Frequency of inspection will be once in 36 months. However, for steel structure that coated with fireproofing, the frequency is depends on the fireproofing inspection interval.

3. RESPONSIBILITIES

The Business Unit is responsible for implementing this procedure. However, Some general category are;

3.1. Operation Representative

- Ensures inspection area is safe for inspection activity.

3.2. Maintenance Representative

- Ensures availability of permit for person entering the work area.
- Ensures all relevant permit-to-works applied and approved before commencement of inspection and repair works.

3.3. Asset Integrity Inspector

- Carry out visual inspection based on the inspection procedure.
- Carry-out improvement of the inspection implementation based on the overall perspective of inspection processes.
- Conduct periodic internal audit on the steel structure inspection program.
- Document all inspection results in Master Data Base.

4. TYPES OF STRUCTURES

Structural equipment consists of structures that support other types of assets, as well as safety and access structures. Typical types of structures found in process facilities may include:

- Steel frames and trusses supporting elevated equipment and piping.
- Pipe racks, piping, and pipeline support piers.
- Derricks and trusses supporting coke cutting equipment, steel stacks, or other equipment or piping.
- Self-supported steel stacks
- Cooling towers
- Heater structures
- Solids storage vessels such as bins and silos, steel tanks.
- Structural frames supporting lifting and conveyance equipment.
- Safety Structures (walking surfaces/platforms, ladders, etc.)
- Other structures that can affect process safety and reliability.

5. INSPECTION METHOD TYPES OF STRUCTURES

The methodology section outlines the plan and method that how the study is conducted. To guarantee the integrity of the steel structure upon its deployment, it is essential for experts to evaluate each individual component in accordance with the relevant standards. The inspection of steel structures includes a comprehensive assessment of raw materials utilized in the construction, welding materials, bolt connections, fire-resistant coatings, and additional components. This discussion will delve into the procedures involved in inspecting steel structures as per established standards. The details are as follows.

5.1. Steel structure inspection for size and flatness

Size deviation represents a critical aspect in the evaluation of the dimensions of steel structures. The size deviation of steel elements must conform to the precise measurements specified in the design documentation, and the allowable values should be consistent with the established technical standards.

It is essential to ensure straightness in two dimensions. This necessity arises from the propensity of components such as steel girders and trusses to experience vertical deformation within their plane and lateral deformation outside of it. Furthermore, steel columns are prone to tilting and distortion along their length.

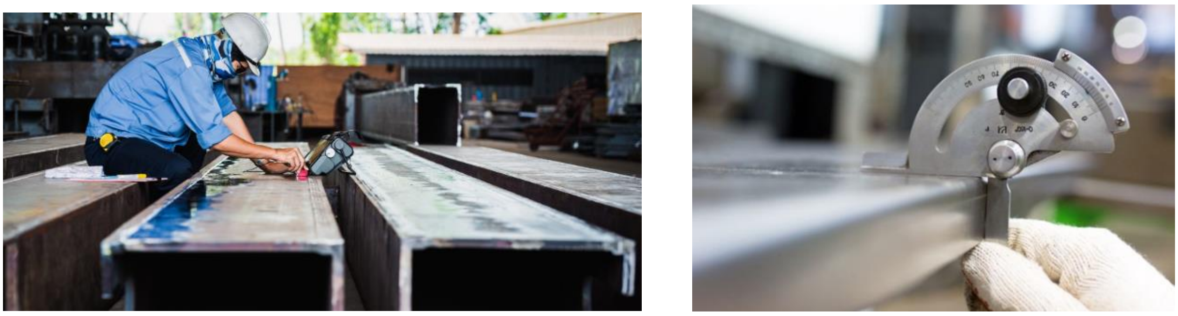

Fig.No:-1 SIZE AND FLATNESS

To evaluate the flatness of the steel structure, technicians may commence the assessment with a visual inspection. During this process, the technician should extend an iron rod or a thin wire between the beam and the truss fulcrum, followed by measuring the inclination and deviation at various points. The inclination of the steel column can be determined using a theodolite or a plumb line, while the deformation of the column can be assessed by utilizing an iron wire or a thin wire stretched between the fulcrums of the steel members for measurement.

5.2. STEEL STRUCTURE INSPECTION FOR CONNECTIONS

When dealing with a connection plate, it's vital to check that its size and thickness align with the necessary specifications. Experts can utilize calipers to evaluate flatness, measure bolt holes, and simultaneously detect any cracks or localized defects.

For bolt connections, a thorough inspection can be performed through visual checks combined with tapping using a hammer, while the tightness of the bolts can be re-evaluated with a wrench. At this stage, paying close attention to the connections of high-strength bolts is particularly important. The number, diameter, and arrangement of the bolts should also be carefully examined to prevent any inconsistencies.

Weld joints can be assessed using ultrasonic flaw detection or radiographic testing methods. After identifying any internal issues within the weld joint, an immediate assessment of the external configuration of the joint is necessary.

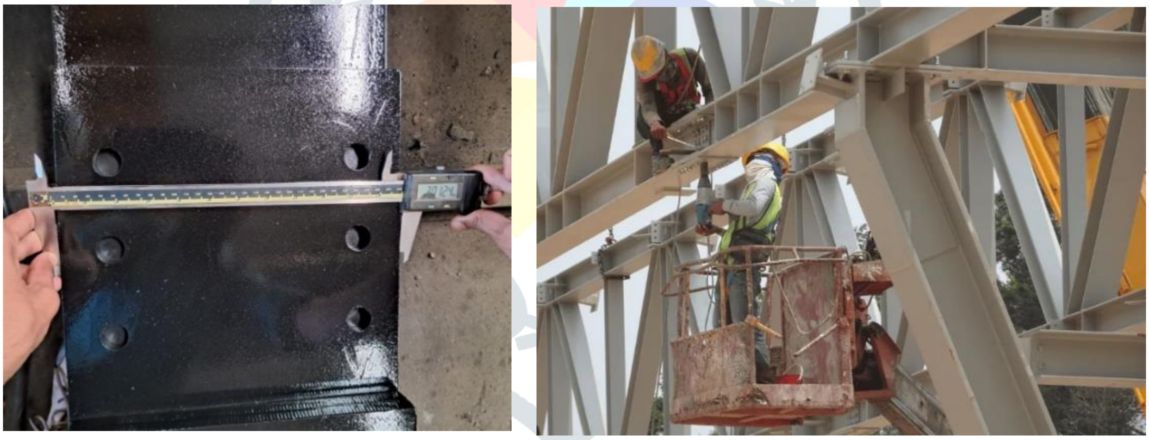

Fig.No:-2 CONNECTIONS INSPECTION

5.3. CORROSION TESTING

Corrosion is the process of material deterioration resulting from chemical or electrochemical reactions with the environment. Steel materials are highly susceptible to rusting in a humid environment. Following corrosion, the steel's cross-sectional area weakens, leading to a significant reduction in load-bearing capacity. Employing thickness measurement devices and vernier calipers is an effective measure for inspecting and detecting corrosion in steel structures.

5.4. VISUAL INSPECTION

Most cracks in steel surface are first detected by visual inspection. The individual elements of steel structures should be visually examined either with the naked eye or using appropriate equipment such as mirrors or telescopic equipment to identify structural defects. Once a crack is found, other non-destructive inspection methods, such as Dye Penetrant and Magnetic Particle, are used to further clarify the extent of crack may be necessary for specific structures from time to time.

The usual and most reliable sign of fatigue cracks is the oxide or rust stains that develop after the paint film has cracked. Experience has shown that cracks have generally propagated to a depth between one-fourth and one-half the plate thickness before the paint film is broken, permitting the oxide to form. This occurs because the paint is more flexible than the underlying steel.

Inspect for loose fasteners. The most reliable sign for loose structural fasteners is the leaching of rust stains from the interface of the connecting elements.

5.5. HAMMER TEST

When elements are tapped lightly with an inspector's hammer, it will help to identify loose plates and fastenings, the extent of corrosion, and effectiveness of corrosion protection. Care must be taken that hammering does not cause unnecessary destruction of protection systems.

Specialist inspection methods, including X-ray, Ultrasonic, Acoustic Emission and Laboratory Analysis of steel samples are beyond the normal scope of Visual Inspections.

5.6. NON-DESTRUCTIVE TEST

Non-destructive testing utilizes the characteristics of sound, light, magnetism, and electricity to detect defects or inconsistencies without causing damage or influencing the functionality of steel components. This method can precisely determine the size of defects.

Depending on the material, structure, manufacturing method, working environment, usage conditions, and specific issues of the tested component, one can anticipate the type, shape, location, and orientation of potential defects. Subsequently, an appropriate non-destructive testing method will be employed. Below are some commonly used non-destructive testing methods:

- Ultrasonic Testing (abbreviated UT)
- Radiographic Testing (abbreviated RT)
- Magnetic Particle Testing (abbreviated MT)
- Penetrant Testing (abbreviated PT)

Conventional destructive test such as Magnetic Particle Testing (MPI) or flaw detection penetrant dye will detect suspected cracking not clearly visible. The local area is to be cleaned to bare metal to perform the testing. The bare metal shall be re-primed with an appropriate paint system if no crack is found.

Where protective coatings are showing signs of deterioration, or where remote faces of steel elements preclude surface inspection, a dry film thickness gauge or ultrasonic flaw detector device should be used to determine relevant thickness of coating or steel section.

Advance non-destructive testing (NDT) shall be carried out on site to further evaluate any defects or discontinuities.

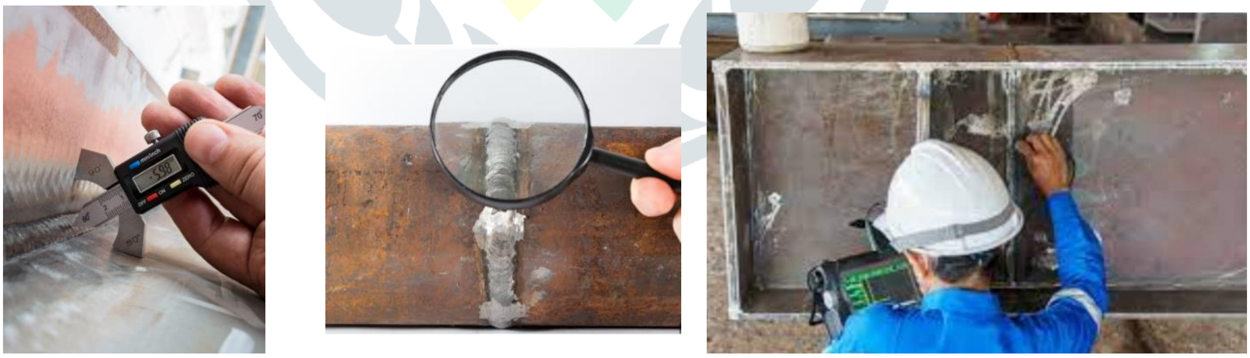

Fig.No:-3 NON-DESTRUCTIVE TEST (NDT)

5.7. STEEL STRUCTURE PERFORMANCE TESTING

To assess the performance of the steel structure, specialists undertake the following stages:

- **Steel Mechanics Testing:** This stage involves the examination of the mechanical properties of steel used in steel structures, such as tensile strength, flexural strength, impact resistance, hardness, etc.

- **Mechanical Testing of Fasteners:** This stage entails the assessment of the mechanical properties of fasteners used in steel structures, such as the coefficient of friction, axial load, etc.
- **Metallographic analysis:** This stage encompasses the analysis of the type of steel used in structures, including microscopic structure analysis, microhardness testing, etc.
- **Chemical composition:** This stage requires experts to conduct an analysis of the chemical composition of the type of steel used in steel structures.
- **Stress test**: This test involves checking and monitoring stress
- changes in key components during the installation and disassembly of steel structures.

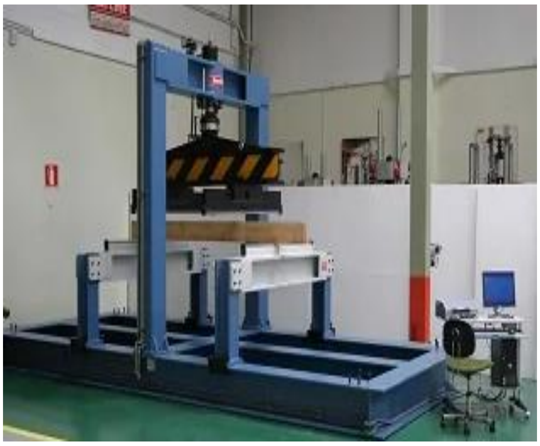

Fig.No:-4 PERFORMANCE TESTING

Fig.No:-5 Generic methods for guide

Selection Guide for Inspection Method

Method	Applications	Advantages	Disadvantages
Visual	Surface discontinuities	Economical, fast	Limited to visual acuity of the inspector
Liquid penetrant	Surface cracks and porosity	Relatively inexpensive and reasonably rapid	Cleaning is needed before and after inspection. Surface films hide defects
Magnetic particle	Surface discontinuities and large subsurface voids	Relatively economical and expedient	Applicable only to ferromagnetic materials
Radiographic	Voluminous discontinuities Surface and internal discontinuities	Provides a permanent record	Planar discontinuities must be favorably aligned with radiation beam. Cost of equipment is high
Ultrasonic	Most discontinuities	Sensitive to planar type discontinuities. High penetration capability	Small, thick parts may be difficult to inspect. Requires a skilled operator.
Eddy current discontinuities	Surface and subsurface can be inspected.	Painted or coated surfaces signal High speed	Many variables can affect the test

6. VISUAL INSPECTION OF STEEL STRUCTURAL ELEMENTS

Visual Inspection (VI), also known as visual testing (VT), represents the most fundamental and traditional method of inspection. At its core, visual inspection involves the examination of a component or piece of structural' s equipment with the naked eye to identify any defects. To enhance the effectiveness of this process, various optical aids such as illuminators, mirrors, and borescopes may be employed. Additionally, the use of cameras, computer systems, and digital image analyzers can significantly augment the capabilities and advantages of visual inspection.

This method is commonly utilized for both internal and external surface assessments of a wide range of structures, including associated with storage tanks, pressure vessels, piping, and other machinery. While visual inspection is relatively straightforward and less technologically sophisticated than other inspection methods, it offers several benefits that make it advantageous. Notably, it is considerably more cost-effective, as it typically requires no specialized equipment—only the expertise of a trained inspector. For similar reasons, it is regarded as one of the simplest inspection techniques to execute.

Visual inspections are often conducted as a preliminary step before employing more advanced inspection methods that can detect flaws not visible to the naked eye, such as subsurface cracks.

Advanced Forms of Visual Inspection: Remote Visual Inspection (RVI) is an advanced form of visual inspection that uses various types of video probes, video borescopes, remotely operated cameras, robotic crawlers, and other specialized tools in order to remotely examine components. In doing so, the risks associated with confined space entry are considerably reduced.

In recent years, unmanned aerial vehicles (UAVs), commonly known as drones, have seen increased adoption and usage for remote visual inspections of structures that are difficult to reach by traditional means, such as flare stacks, elevated pipe trays, and cooling towers.

6.1. Pre-Inspection Investigation

Prior to undertaking a visual Inspection, Inspector should review the available relevant historical information for the structure such as: -

- Available inspection or any investigation reports
- Maintenance history
- Outstanding defects and planned Major Periodic Maintenance
- Deficiencies identified for future observation
- Structural issues that have been recorded since last inspection

6.2. Preparation for Inspection

In preparation for the inspection, Inspector should liaise with the Asset Group Representative to ensure the appropriate arrangements are in place to undertake the inspection access arrangements.

6.3. Visual Inspection

In general, steel deteriorates in service in the following ways: -

i. Erosion or corrosion at exposed surfaces or at concrete interfaces
ii. Cracking in elements or welds
iii. Relaxation of fastenings (loose bolts) – To re-tighten loose bolts, refer to the Table 4 for the required torque value.
iv. Distortion due to overload, or direct impact of the imposed load
v. Fatigue from repetition of external loading
vi. Paintwork condition
vii. Deflection (deflection in steel elements normally small).

6.3.1. Assessment of Previously Reported Defects and Monitor

At the start of inspection procedure, the Inspector should review the status of previously reported defects, including those require monitoring. Depending on the rate of deterioration of the defect the Steel Structure Inspector should either record: -

- No Change – The original deficiency category and repair priority (where appropriate) allocated to the deficiency does not change.
- Re-Assess – The deficiency is reassessed, and a new deficiency category and repair priority recorded
- Completed – If the defect has been repaired but still identified as an outstanding defect, the Steel Structures Representative should be notified to have it closed through SAP.
- Outstanding - If a defect has been reported as repaired but still outstanding, the Steel Structures Representative should be notified.

Tools	Type of Defect
Scale or calipers	Cracks, determining metal thickness
Pit Gauge	Depth of pits and extent of their occurrence.
Scraper	Samples of corrosion products or damaged coatings
Torque Wrench	Bolts loosened
Ultrasonic equipment	Determining metal thickness

Table 1: - Inspection Tools for Defects of Steel Structures

6.3.2. New deficiency identification

When Inspector identifies a new defect, the following information should be recorded: -

- Type of element
- Location of element
- Assessment of Defect (Category A –D and M) – Refer to Table 2
- For defect Category A-D, assign a Repair Priority and a specific date for rectification (refer to Table 3)
- For Defect Categories A and C, impose an immediate mitigation strategy as deemed necessary
- Defect size
- A brief description of the defect. Where the defect is likely to cause a reduction in strength, provide estimate of

reduction in cross sectional area of structural element or loss of structural adequacy.

- Photographic records of all critical defects. Where defects are repeated, only typical defects photographs are required.

It should be noted for Category A to C defects the Inspector should communicate urgently with the Steel Structure Representative to implement immediate mitigation strategies and arrange further assessment within the prescribed timeframes. All verbally agreed actions should be documented in the inspection report.

For Category M, Monitor, the Inspector can allocate the defect: -

- To the Steel Structures Representative to review, or
- For re-assessment at the next inspection.

CATE GORY	TYPE OF DEFECTS	ACTION/REPAIR PRIORITY CODE
A	Cracks	Immediate / E
B	Deflection	Immediate / E
C	Loose of fasteners	Immediate / P1 – depending on how many bolts loosened
D	Delamination of paint	P1 or P2
M	Regular checks	Monitor

Table 2: - Category of Defects

REPAIR PRIORITY CODE	RECTIFICATION PERIOD
E - Emergency	Immediately start
P1 – Priority 1	Break into Daily Schedule, logically it means to start working on the request within 1 day.
P2 – Priority 2	Break into Weekly Schedule, logically it means to start working on the request within 1 week.
P3 – Priority 3	Optimize resources, to be scheduled optimizing available resources.
P4 – Priority 4	Requires shutdown of equipment.

Table 3: - Repair Priority Codes

Thread Size		Stress Area (in2)	Torque		Induced Load (lbf)
UNC/UN	Millimeter		ft-lb	N-m	
½” – 13 UNC	12	0.142	76.1	103	9.135
5/8” – 11 UNC	16	0.226	151.7	206	14.560
¾” – 10 UNC	20	0.334	268.6	364	21.490
7/8” – 9 UNC	22	0.462	433.9	588	29,750
1” – 8 UNC	24	0.605	650.4	882	39,025
1 1/8” – 8 UN	28	0.790	840.0	1139	44,800
1 ¼” – 8 UN	32	1.000	1181.3	1602	56,700
1 3/8” – 8 UN	34	1.233	1602.1	2172	69,909

Note: - ASTM A325 - Standard Specification for Structural Bolts, Steel, Heat Treated 830 MPa Minimum Tensile Strength. It defines mechanical properties for sizes M12–M36

Table 4: - Recommended Tightening Torques and Induce Loads as per ASTM A325

7. ELEMENT CONDITION ASSESSMENT GUIDELINES

The following guidelines are provided to assist Inspector to assess the condition state of steel elements.

7.1. CONDITION STATE 1

- The paint system is generally sound with only minor chalking, peeling or curling but with no exposure of metal.
- All welds and bolts are in good condition with no movement of plates or section in the elements.

7.2. CONDITION STATE 2

- Spot rusting of the paint system to 5% surface area is occurring and the paint system is no longer effective. No corrosion of the section has occurred.
- All welds and bolts are in good condition with no movement of plates or section in the elements.

7.3. CONDITION STATE 3

- Some surface pitting may be present with active corrosion occurring in isolated areas, but no loss of section area has occurred which will affect the strength of the element.
- The paint system has broken down with rust spotting to 10% and surface pitting.
- Nuts and bolts may be corroded but are still tight and no cracking of welds has occurred.

7.4. CONDITION STATE 4

- Corrosion is well advanced, and loss of section has occurred having a detrimental effect on the strength of the element, i.e. a flange may be badly corroded over a sizable length.
- Bracing may be broken
- There may be some cracking of the welds between the plates.
- Bolts may be severely corroded and no longer carrying full load or functioning as intended.
- The paint system has completely broken down with cleaning back to bright metal required before repainting.

8. ADDITIONAL INSPECTION REQUIREMENTS

When undertaking inspection for a steel structure, Inspector shall provide the following additional information:

8.1. PAINT CONDITION RATING

Paint Condition Ratings are to be assigned by the Steel Structures Engineer to reflect the condition of the surface coating. for the overall structure. The ratings are defined as follows: -

- Poor - Paint broken down throughout. Program to paint within 10 years.
- Fair - Paint broken down locally. Touch up paint as required within 5 years.
- Good - Paint is satisfactory condition

9. INSPECTION REVIEW

9.1. DEFECTS

The Maintenance Representative should review, within the specified timeframes: -

- All Category A to D defects
- All Category M defects where the Inspector has requested further review
- The Steel Structure Representative in Maintenance team has authorization to change the defect category, repair priority and rectification date reported by Inspector. The Inspector's original assessment must be kept on record.

Where the Maintenance Representative has concerns over specific defects, f further advice may be sought from the Steel Structure Engineer who undertook the last Engineering Inspection. Where written advice has been provided, the advice should be filed with the inspection report.

9.2. MITIGATION/MAINTENANCE WORK

9.2.1. CORRECTIVE MAINTENANCE

The Maintenance Engineer should allocate the corrective maintenance work to be actioned in accordance with the agreed repair priorities and rectification dates. The Maintenance Engineer should also arrange for any short-term mitigation actions to be implemented.

9.2.2. PREVENTIVE MAINTENANCE

For preventive maintenance work, the Maintenance Engineer should review the outcomes of the Visual Inspection against the proposed repair method.

9.2.3. OVERALL REVIEW OF INSPECTION REPORT

Inspection reports for each PPM inspection shall be created and recorded in Meridiam or any other similar inspection database. For any other type of inspection such as corrective maintenance inspection, it is subject to the Civil Inspection Specialist justification based on the criticality of each issue.

Meanwhile, the inspection check lists (refer to Table 5) and forms in each inspection procedure will be utilized as and when needed basis subject to the justification of Civil Inspection Specialist.

Steel Structure Inspection Checklist				
Site Location:		Date:		
Section Location ID:				
Inspected By :				
Instructions: For each item indicate Ok, Needs Repair, or N/A (Not Applicable). Document any deficiencies at the bottom of the form. No more than one area should be assessed per checklist.				
Item	**Inspection description**	**Yes**	**No**	**N/A**
	Are there any signs of corrosion evidence such as rust, scale and holes, on steel structure surfaces?			
	Is there a scale mark detected after the soundness check on the steel surface using inspection hammer?			
	Are there any loosening of structural connections (as indicated by misalignment of mating surfaces and by looseness or distortion of structural members)?			
	Is there any sign of deformation or distortion occurred on structural members?			
	Is there an abrasion of steel structures (as indicated by a worn, smooth, polished appearance)?			
	Is there any weld deficiency			
	Is there any coating deficiency			
	Is there any further engineering support is needed based on the extent and type of corrosion, structural damage or any other significant observations?			
	Is there require any NDT test/checking (e.g. ultrasonic inspection, magnetic particle inspection, etc.) to further evaluate the condition of the structural steel members?			

Table 5: - Inspection General Check List of Structural Steel

10. ENVIRONMENTAL, HEALTH AND SAFETY

The work shall be executed in accordance with the approved Job Safety Plan.

- Before starting the work, this work procedure shall be discussed to all personnel involved.
- Responsible Maintenance Representative will monitor all activities during the construction.
- Toolbox Talks to be done at the start of each work.
- Safety protection such as wearing of safety helmets, sturdy leather steel toe cap shoes and eye protection while on site in the execution of work is mandatory.

11. CONCLUSION

Thorough industrial best practices for the inspection of steel structures are crucial for guaranteeing the safety, dependability, and durability of these structures within industrial settings. These practices cover a broad range of applications, including various structures like platforms, frames, storage tanks, and pipelines. They establish explicit responsibilities for all parties involved, such as inspectors, engineers, and maintenance personnel, thereby ensuring accountability and a methodical approach to execution.

The inspection process integrates various methods, including visual inspections, non-destructive testing (NDT), and advanced monitoring techniques, to assess structural integrity accurately. Conditional assessments help identify early signs of deterioration, enabling timely mitigation and corrective maintenance. Additionally, environmental health and safety considerations play a critical role in protecting personnel and minimizing environmental impact during inspections and maintenance activities.

By adhering to these comprehensive practices, industries can not only prevent structural failures but also enhance operational efficiency, reduce maintenance costs, and comply with regulatory standards. These guidelines serve as a roadmap for achieving excellence in steel structural inspection and maintenance, ensuring long-term sustainability and safety.

12. References

[1] Andreani, J., 2019, "An Effective Structural Integrity Program as Part of a Comprehensive Mechanical Integrity Program," Inspectioneering Journal, 25(6).

[2] ASNT, 2016, "Codes and Standards Bodies Involved in NDT Industry," American Society for Nondestructive Testing.

[3] ANSI/AISC 303-22, Code of Standard Practice for Steel Buildings and Bridges, Section 8. Quality control

[4] Lesiuk, G.; Szata, M.; Bocian, M. The mechanical properties and the microstructural degradation effect in an old low carbon steels after 100-years operating time. Arch. Civ. Mech. Eng. 2015, 15, 786–797. [Google Scholar] [CrossRef]

[5] Lesiuk, G.; Szata, M. Aspects of structural degradation in steels of old bridges by means of fatigue crack propagation. Mater. Sci. 2011, 47, 82–88. [Google Scholar] [CrossRef]

[6] De Jesus, A.M.; da Silva, A.L.; Correia, J.A. Fatigue of riveted and bolted joints made of puddle iron—An experimental approach. J. Constr. Steel Res. 2015, 104, 81–90. [Google Scholar] [CrossRef]

[7] ANSI/AWS B1.10 American National Standards Institute/American Welding Society. ìGuide for the Nondestructive Inspection of Welds,î Designation: ANSI/AWS B1.10-99, Miami, FL.

[8] ANSI/AWS QC1, American National Standards Institute/American Welding Society. ìStandard for AWS Certification of Welding Inspectors,î Designation: ANSI/AWS QC1-96, Miami, FL.

[9] ASTM A36/A36M-01(Specification), Standard Specification for Carbon Structural Steel

[10] Daniel Balageas, "Introduction to Structural Health Monitoring"