



BEng Mechanical & Manufacturing Engineering
Wales Institute of Science & Art

Blast Furnace Skip Hoist – Wire Rope Life Extension

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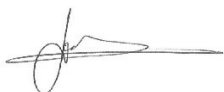
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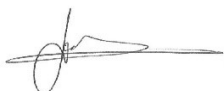


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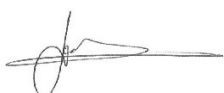


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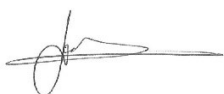


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Abstract

The blast furnace skip hoists are critical to the production of iron and form a vital part of the production chain. This project explores the feasibility of extending the tonnage based frequency of wire rope replacement on a blast furnace skip hoist system. In order to do this in depth, research has been carried out into wire rope failure mechanisms and the application of magnetic wire rope inspection (MRT) and the associated standards.

The safety assessment was carried out with the use of MRT which is the primary detection method for internal defects in wire ropes. The results were scrutinised to identify potentially dangerous defects which could prohibit the life extension project. It was identified that internal corrosion was present along with a number of internal broken wires, however, this may have been due to external factors during removal. Additionally, maintenance plans were discussed with improvement suggestions made within the project report.

It is of the opinion that with the correct maintenance and care, the wire rope change frequency could be extended with the use of ongoing monitoring techniques such as MRT and visual examination to level of the ISO 4309 standards.

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1. Introduction

Tata Steel is the largest steel company in the UK and it provides a vital foundation for many of the country's key strategic supply chains, including the automotive and construction industries. Tata Steel supplies almost 50% of UK carmakers' steel requirements with more than 3 million tonnes of steel produced per year and employs more than 8,000 people with an annual turnover of more than £2.6bn [1]. Pivotal to this steel production is the integrated steelworks at Port Talbot which is the location for two blast furnaces that produce the iron for the steel making process. In order for the blast furnace to continually produce iron, the process is required to have a constant input of raw materials such as iron ore, coke and sinter. Facilitating this steady supply of raw material into the blast furnace is the skip car hoist which is operated 24 hours a day, 365 days a year.



Figure 1 - Port Talbot blast furnace showing skip car incline

The skip car hoist system makes approximately 26 cycles an hour which equates to material loading every 2.3 minutes. The skip car hoist is of the highest criticality within the production system as without raw material, the plant cannot produce iron which clearly impacts costs. For context, if the hoist was to fail, an idle blast furnace costs Tata Steel approximately £30-50k per hour in downtime and the blast furnace can only continue to run for a maximum of two hours without raw material input depending on production rates. The primary reason for

this is the temperature at the top of the blast furnace increases from 120°C to in excess of 300°C which triggers process safeguards.

The main subject for this project is that of the lifting media required for the skip hoist operation. The wire ropes of the skip car hoist are currently changed out on a frequency basis of 2.5 million tonnes of raw material loaded into the blast furnaces. This current 'run rate' equates to the wire ropes being replaced approximately every 18 months, depending on variable factors such as blast furnace uptime, material availability and the availability of the furnace to take a planned stop to change the wire ropes at the required dates. It is the hypothesis that the lifecycle of the wire ropes has the potential to be increased with engineering investigation and utilisation of Magnetic Wire Rope technology (MRT). This is due to the 6 monthly visual and quantitative inspections carried out by the subject matter expert (SME) and the results not identifying any serious degradation to the wire ropes. This has been discussed in depth with the blast furnace engineering management team and the project explores and carries out this opportunity for potential life extension. Research has been carried out on the use and limitations of MRT for the inspection of wire ropes in general and specifically on the blast furnace wire ropes. Common failure modes of wire ropes has been explored in detail making specific links back to the current wire ropes in use. Depending on the results of the MRT and ongoing improvements to the current maintenance strategies, this could result in an increased lifecycle for the wire ropes which would have clear cost savings for Tata Steel UK. This project also further supports Tata Steel's "Drive to Save" campaign without compromising safe operations.

1.1. Aim and Objectives

1.1.1. Aim

The aim of the project is to research and carry out wire rope testing with the use of MRT with a view to increase the lifespan of the skip hoist wire ropes to maximise blast furnace uptime while ensuring that an acceptable level of safety is upheld.

1.1.2. Objectives

1. Provide evidence in support of increasing the lifespan of the skip hoist wire ropes
2. To increase the overall safety of the wire ropes
 - a. Analyse and improve maintenance plans and activities on the wire ropes to identify potential improvements.
3. Carry out MRT testing on the skip hoist wire ropes
 - a. Scrutinise results to accordingly advise on reasonable suggestions for life expectancy.
4. To implement underutilised technology on the skip hoist wire ropes within the blast furnace area at Tata Steel Port Talbot and site wide in the longer term.

1.2. Skip Car Hoist Operation

The skip car hoist system consists of two skip cars (as seen in Figure 2) working in tandem which are capable of transporting loads up to 25t per car that are hoisted up a 55° inclined rail track to a height of 73.56m. The skip hoist operation is implemented upon a Qualter Hall wire rope drum and hydraulic brake unit powered by 2 x ABB motors. The skip hoist is a position control system that follows a pre-determined speed profile (as seen in Graph 1) which starts at the skip pit, located at the bottom of the skip bridge, and ends at a known tipping point above the furnace receiving hopper. The winch drum, skip pit and tipping point are shown as A, B and C respectively in Figure 5.

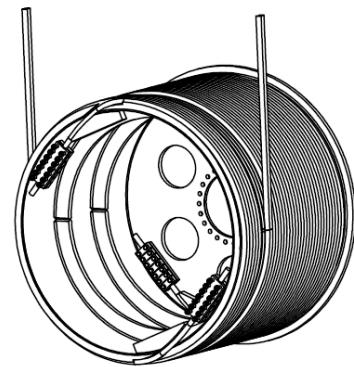


Figure 2 - Skip car for material hoisting and wire rope drum [2]

The control of the skip hoist is carried out by an ABB ACS800 PLC that sends a speed reference to 2 ACS800 drive units; these control the speed of 2 winch motors. For safety reasons, the system is capable of hoisting loaded skips on only 1 motor. The distance over which the skip moves from the bottom of the skip bridge, under the holding hopper, is called the creep out zone, and the speed is known as the creep out speed. This speed is limited to 0.3m/s, with a creep out distance of 1.3m.

As a loaded skip car moves away from the holding hopper, the second skip moves away from the tipping point, hence the creep out zone and speed is equal in value for the initial movement at either the top or bottom of the skip bridge. Once the skip clears the creep out zone, it accelerates to its full speed of 3.05m/s. After a set period, the system will then decelerate the skips to the creep in zones, to a speed of 0.45m/s. This zone starts 2m away from the final 55° tipping angle stopping position of 73.56m [3]. The skip bridge is at a 60.5° incline.



Graph 1 - Skip car speed vs Position [3]

There are a total of 4 wire ropes that act as the lifting media for the skip cars. There are two wire ropes per skip car in order to offer an adequate safety margin to the given minimum breaking load of the wire rope. Again, due to safety margins, the load could still be hoisted with a single wire rope. The specification of the wire ropes is 48mm Dyform 6 at 195m long as can be seen in Appendix A. The skip cars are connected to the wire ropes via solid thimble eyes with a hand spliced end termination via a compensation system to equalise the loading on each wire rope as seen in Figure 3. The termination is secured to the car using a load pin which allows the wire rope termination transverse movements which helps prevent fatigue. This also allows ease of maintenance on the skip cars.



Figure 3 - Skip car terminations and compensation arm

1.2.1. Blast Furnace GA Drawing

The following drawing shows the blast furnace hearth location in relation to the skip hoist trestle which for context and can be compared with Figure 1.

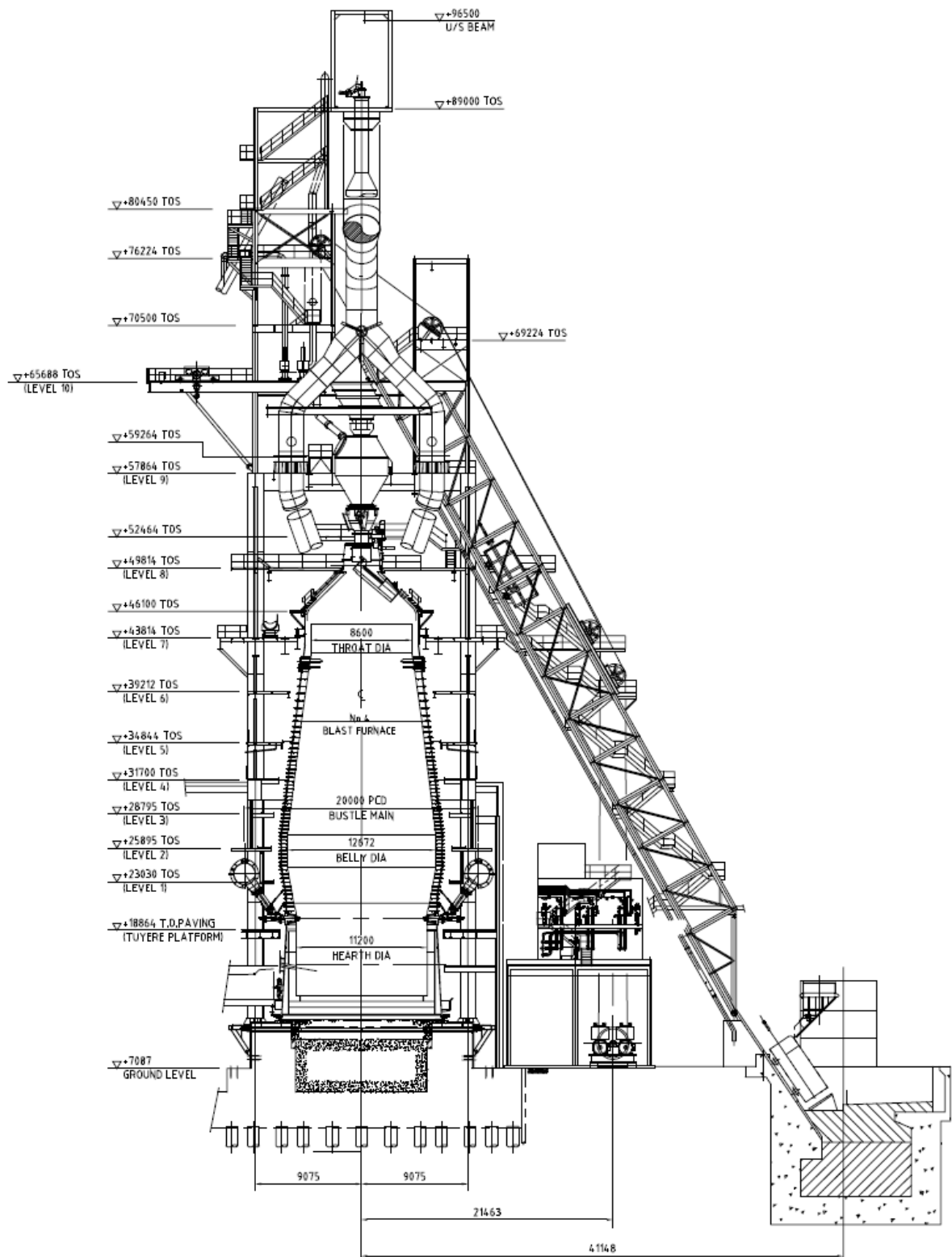


Figure 4 - Blast Furnace general layout [4]

1.2.2. Skip Car Hoist GA Drawing

Skip car hoist drawing showing reeving route for the wire ropes and locations of key areas as identified in the caption.

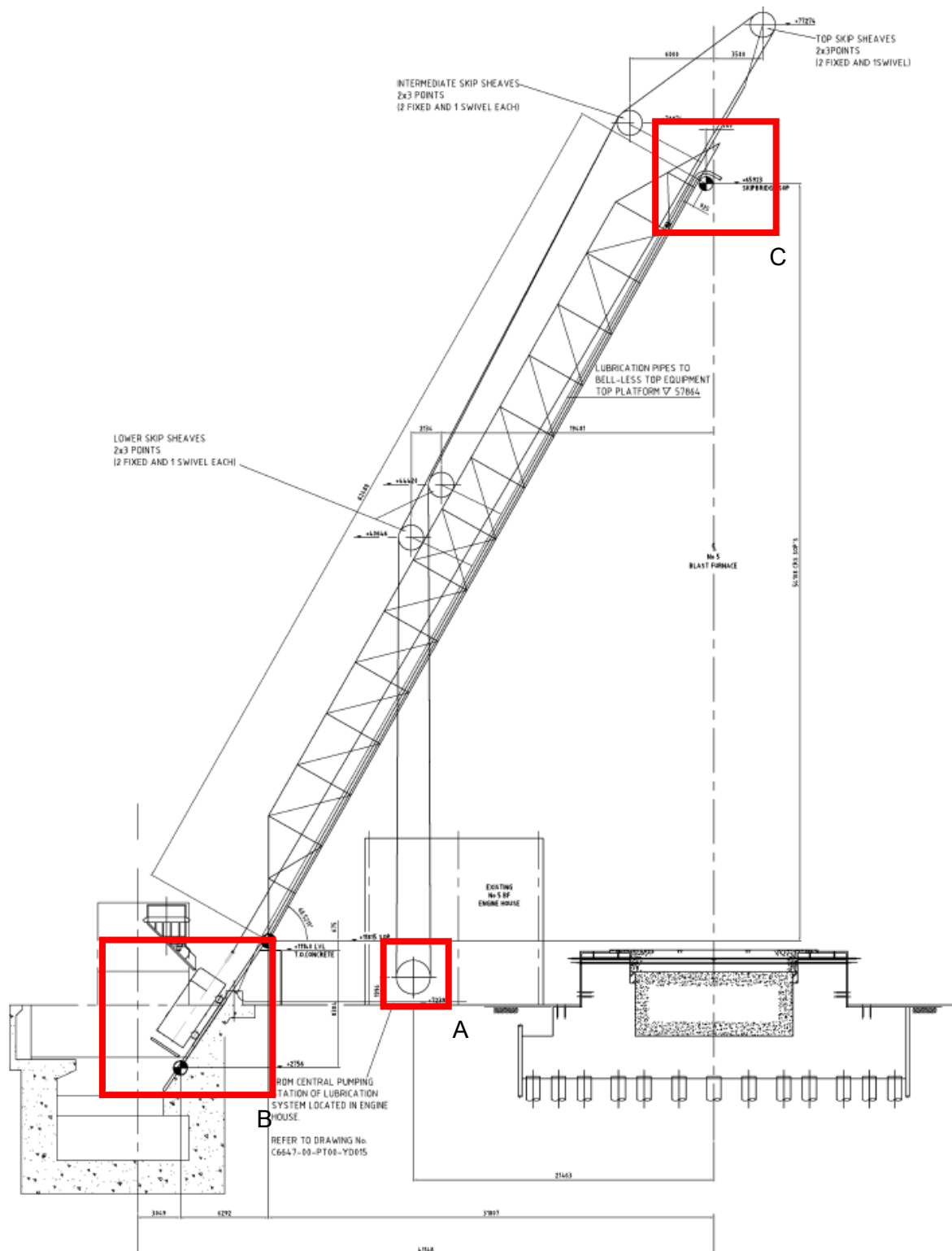


Figure 5 - Skip car hoist - (A) Winch drum (B) Skip pit (C) Tipping point [5]

1.2.3. Wire Rope Axial Force Calculations

If the acceleration zone is considered as the section where the highest force will be acting on the wire ropes given that:

$$T = mg + ma$$

Where: T = Tension force (N)

m = Mass (Kg)

g = Gravity (m/s^2)

a = Acceleration (m/s^2)

Equation 1 - Tension force

Therefore, the higher the acceleration, the higher the tension force which enables other areas of the velocity profile in Graph 1 to be disregarded. In addition, the friction coefficient (μ) will be treated as 0.5 [6] as the skip car runs on a dry steel track with steel wheels. The calculations consider a mass of the skip car at 40,000kg running up an incline of 60.5° as per Figure 5 moving at a constant velocity.

Using Equation 2 to calculate the force on the wire rope:

$$F = ma$$

Equation 2 - Basic force

Equation 2 is then transposed to work out the average acceleration within the accel zone on the velocity profile in Graph 1.

$$\dot{a} = \frac{vf - vi}{t}$$

Where: F = Force (N)

vf = Velocity - final (m/s^2)

vi = Velocity initial (m/s^2)

t = Time (seconds)

$$\dot{a} = \frac{3.05 - 0.3}{5} = 0.55m/s^2$$

So the force on the wire ropes on a flat plane is:

$$F = (40 \times 10^3) \times 9.81 \times 0.55 = 215.82 \text{ kN}$$

Now calculating the force at the 60.5° angle incline of the skip hoist track :

$$F\theta = mg \sin\theta + F \cos\theta + mg \cos\theta \mu$$

Equation 3 - Force on an inclined plane

$$F\theta = (40 \times 10^3) \times 9.81 \times \sin(60.5^\circ) + (215.82 \times 10^3) \times \cos(60.5^\circ) + (40 \times 10^3) \times 9.81 \times \cos(60.5^\circ) \times 0.5$$

$$F\theta = 341.53 \times 10^3 + 106.27 \times 10^3 + 96.61 \times 10^3 = 544.41kN$$

The calculated line pull force on the wire ropes is essential to work out the factor of safety (FOS) for the wire ropes to ensure that there is an acceptable level of safety upheld and that the wire ropes will stay in their elastic region and not exhibit any plastic deformation.

This force is divided between two wire ropes so the approximate individual line pull force is 272.2kN. Utilising the force calculated, the safety factor can be calculated considering the Bristar Dyform 6 wire rope has a minimum breaking load (MBL) of 1942kN.

$$FOS = \frac{MBL}{LF}$$

Where: FOS = Factor of safety

MBL = Minimum breaking load (kN)

LF = Line force (kN)

$$FOS = \frac{1942}{272.2} = 7.1$$

Equation 4 - Factor of safety

As can be seen from the calculations, the factor of safety is calculated to be 7 to 1 only taking into account the line pull. Now it can be taken into account that the efficiency of a hand spliced termination which is used on the skip car hoist has an efficiency rating of 80% [7]. So we can calculate the system safety factor as follows:

$$FOS = \frac{1942 \times 0.8}{272.2} = 5.7$$

This margin is perfectly acceptable for the operation that is being carried out and the factor of safety and maximum line pull are further indication that the project aim can be met where an acceptable level of safety is upheld.

Note: The calculations that have been performed are approximations as there will be errors derived from the velocity profile and the fluctuating mass of the skip car.

1.3. Roles and responsibilities

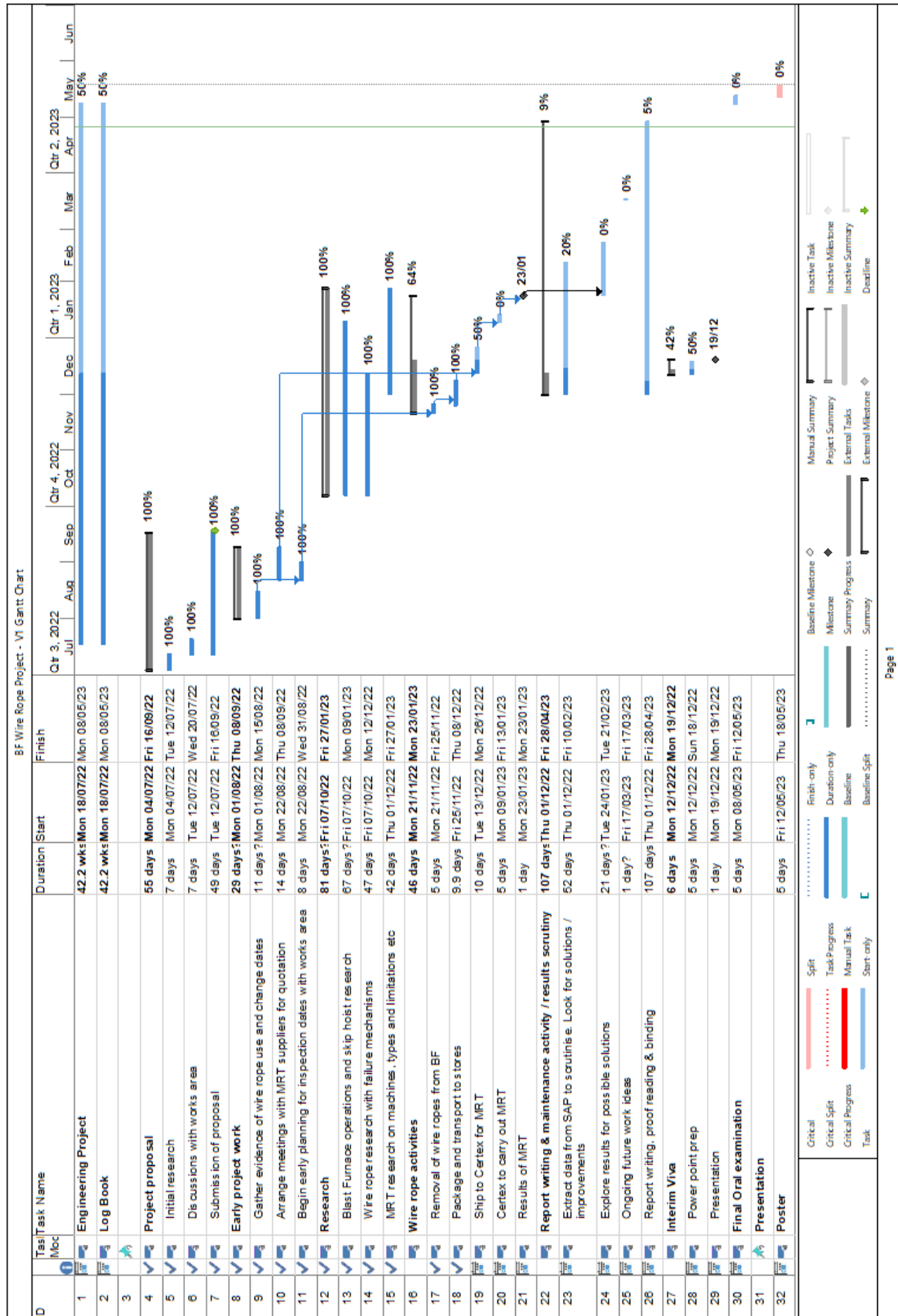
Given the number of people included within the execution of the project and the autonomy of the roles, it was important that the roles and responsibilities were set out early in the project. This can be shown in Table 1.

Company / Persons	Role / Responsibility
John McDyer	To act as project manager ensuring activities happen on time including obtaining all quotations and coordinating activities such as shipping of the wire ropes. In addition, to achieve the aims of the project, scrutinise all data and research all relevant information to make informed decisions.
Blast Furnace Engineering team	To facilitate the removal of the skip hoist wire ropes and to ensure safety of the contractors while on site at the blast furnaces. This includes arranging all required permits and isolations for the safe and compliant removal. Review the outcome of the project proposals and implement within the blast furnace if feasible.
King Site Services	To carry out the wire rope change as per the procedure in Appendix C and spool the wire ropes ready for shipping.
Certex	To carry out MRT testing of the wire ropes at their depot: - Fit Reels to winch - Pay out ropes and clean with cleaner/wiper - Once rope is clean, MRT will take place - Data reviewed and report generated and signed off - Dispose of ropes

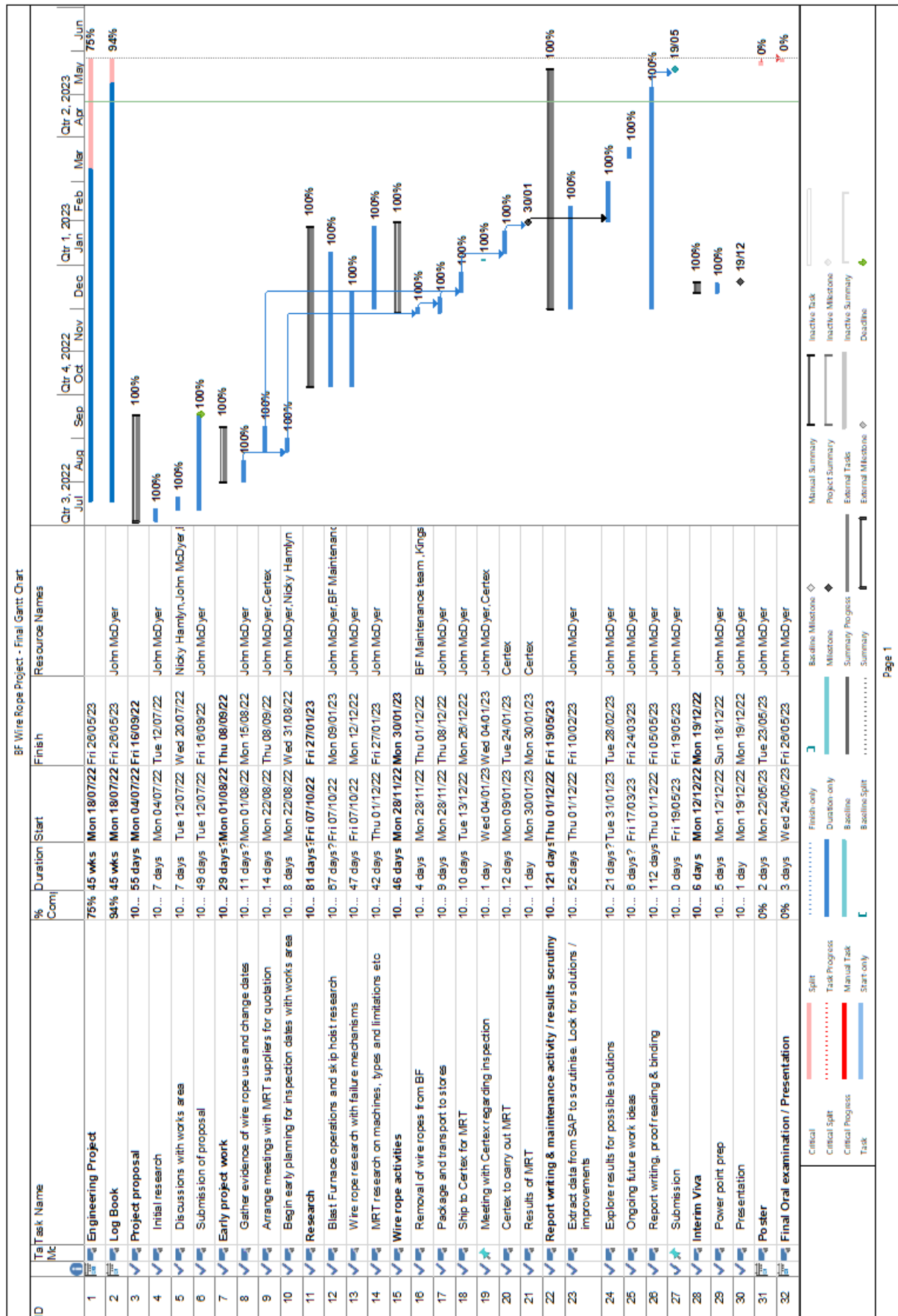
Table 1 - Roles and responsibilities

2. Project Time Management

2.1. Working Project Plan



2.2. Final Project Plan



2.3. Project plan amendments

- a. The initial changes to the project plan were primarily concerned with the blast furnace ability to come off line. In order to remove the wire ropes from the blast furnace skip hoist, a planned stop is required for a duration of approximately 12 hours which wasn't available at the time. In addition, the original plan had aimed to remove a different set of wire ropes from blast furnace 5 a number of weeks earlier, however, it would appear that the blast furnace contractor team did not understand the requirement for the full 195m of wire rope to be in tact to conduct the MRT. The final delay was around one week once a set of wire ropes had been identified for removal.
- b. Due to the availability of the contracting team, the wire ropes were left unspooled for a period at the rear of the blast furnace area. This caused a delay in the ability to package and ship the wire ropes to Certex (MRT supplier). This was due to the inability to obtain quotes from the courier as the package size and total weight was unknown at this point. However, even due to these delays, the wire ropes arrived at Certex's depot in Montrose as per original plan.
- c. An area where project time was reclaimed was the efficiency of the engineering team at Certex. The meeting to discuss the method of inspection and descriptive nature of the report required happened on the 4th January 2023.
- d. Due to machine availability at Certex Montrose, the inspection was delayed by 11 days. The MRT also took a 10 days to undertake which was unexpected. This was due to the two wire ropes requiring thorough cleaning which was more difficult than originally understood.
- e. Results of the MRT concurrently also arrived 7 days later than anticipated on the 30th January 2023.
- f. Finally, the project as a whole moved to a final completion date of the 26th May 2023 from the original plan of 8th May 2023.

3. Prior Research and Contextualisation

3.1. Steel Wire Rope Structure and Failure Mechanisms

Steel wire ropes are utilised by most industries throughout the world in a multitude of applications, from bridges, mooring, cranes, National Grid power lines and transmission of mechanical power, as can be seen in Figure 6. They consist of several steel wires twisted together to make a structure with mechanical properties combining axial strength and stiffness with bending flexibility. In the great majority of applications, steel wire ropes are subjected to several mechanisms of damage. These mechanisms can lead to the premature break of the rope components causing its sudden and unexpected failure. However, in general, due to their structure, they tend to show signs of fatigue prior to total failure [8].



Figure 6 - Examples of wire rope use [9] [10]

Wire ropes are generally regarded as an expendable component and the load rope requires replacement when inspection shows that its condition has deteriorated and further use would not be suitable for safety reasons. By following well-established principles, such as those detailed in various standards, the Lifting Equipment Examiners Association (LEEAA) code of practice, and any additional specific instructions provided by the 'original equipment manufacturer' (OEM) of the crane or hoist and/or by the manufacturer of the rope, this rejection criteria should never be exceeded. When correctly applied, the discard criteria given in full in BS ISO 4309, is aimed at retaining an adequate safety margin [11]. Firstly, it is important to understand the structure of a wire rope and the damage mechanisms in order to carry out safe inspections. It is also important to ascertain the root cause of failure to prevent future occurrences.

3.1.1. Structure and Basic Properties

A steel wire rope is made up of individual, non-alloy, carbon steel wires spun into a strand. A number of strands are closed over a central core, thus producing a rope. The number and size of wires must offer the best compromise possible between large wires for maximum corrosion protection and resistance to abrasion, and smaller wires for the necessary flexibility and handling [12]. The four main components of a wire rope are shown in Figure 7 and it is essential that the wire rope is selected correctly for its purpose. Wires are the smallest component of wire rope and they make up the individual strands in the rope. Wires can be made from a variety of metal materials including steel, iron, stainless steel, monel, and bronze. The selection of the wire material is primarily related to the corrosion properties required for the application. The wires can be manufactured in a variety of grades that relate to the strength, resistance to wear, fatigue resistance, corrosion resistance, and curve of the wire rope. The wires themselves can be coated but are most commonly available in a “bright” or uncoated finish. Strands of wire rope consist of two or more wires arranged and twisted in various specific arrangements. The individual strands are then laid in a helical pattern around the core of the rope. The outer strands are the primary load carrying component of a wire rope [13]. The stranding method is a very important factor as this has consequence to where the concentration of stresses are on the axis of the wire. The cross stranding method causes wire crossings between the wire layers within the strand, resulting in high stress concentrations in the local area. However, with the parallel stranding method, all the wires are arranged parallel in the strand structure, thus a continuous linear contact is achieved. The result is a reduction in compressive stress of the wires which is why hoist ropes tend to be parallel lay. The benefit of cross laying a wire rope strand is to increase its flexibility, however, the wire rope would be prone to internal wire breaks. An example of the stranding methods can be seen in Figure 8.

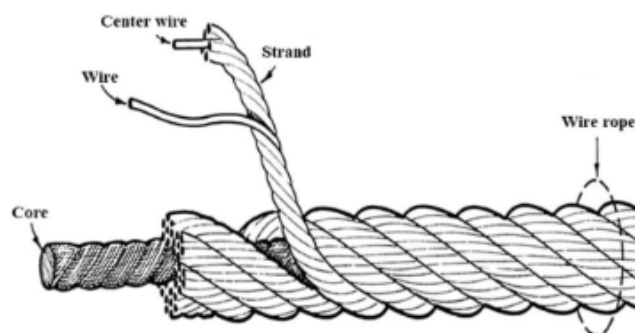


Figure 7 - Components of a wire rope [14]

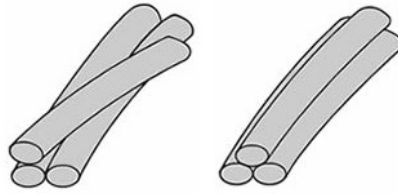


Figure 8 - Cross lay and parallel lay wires [15]

The core of a wire rope runs through the centre of the rope, supports the strands and helps to maintain their relative position under loading and bending stresses. Cores can be made from a number of different materials including natural or synthetic fibres and steel [13]. Wire rope cores come in three categories which are fibre core (FC), wire strand core (WSC) or independent wire rope core (IWRC). A FC is generally not used for heavier duty operations so will not be considered in this research, however, wire stranded core and independent wire rope core are more generally used in industry. If the steel core of the rope consists of a single strand, the term WSC is used and generally has a 15% increase in strength over FC due to the increase in metallic section [15]. If the steel core of the rope consists of a steel wire rope, the term IWRC is used. Examples of these can be seen in Figure 9. [12].

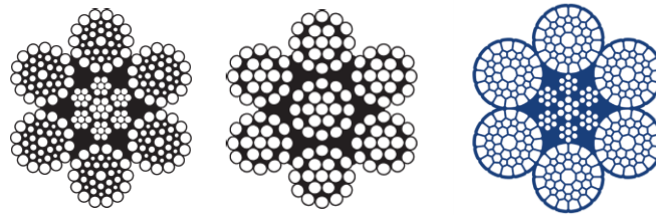


Figure 9 - 6x36 IWRC & 6x19 WSC & 6x41 IWRC as used on the skip hoist. [16]

Steel wire ropes come in a variety of tensile strengths and are selected depending on their requirements including safety factor, number of falls in a crane rope, and minimum breaking load. Table 2 shows the common tensile strengths available for wire ropes, and, for reference, the skip hoist wire ropes which are considered in this research are of a 1960N/mm² tensile strength.

Rope Grade	Wire Tensile Strength Grade	
	Minimum	Maximum
1770	1570	1960
1960	1770	2160
2160	1960	2160

Table 2 - Wire rope tensile grades in N/mm² [11]

Wire ropes come in an array of constructions dependant on their use and resilience requirement, however, the skip hoist wire rope is of a 48mm 6x41 IWRC construction which is a good general purpose hoisting rope. The ropes are also specified to be of a lang lay

where by the wires in the strands and the strands in the rope are twisted in the same direction which is seen in Figure 10. Lang lay wire ropes are selected for their flexibility, fatigue and abrasion resistance and long life due to their greater contact surface leading to a lower unit pressure between the wires [17].

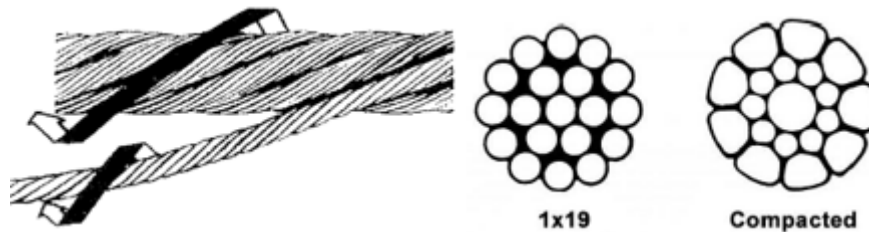


Figure 10 - Lang lay rope [17] and compacted [18]

In addition, the rope is also specified as a compacted wire rope where by the wires are swaged to produce a tighter rope which reduces the gaps between the wires. Compacted wire ropes typically exhibit a 30% increase in breaking strength and 25% less stretch over traditional ropes, as well as providing better crush resistance and fatigue life due to surface contact [18] [19]. Lastly, the wire rope has a plastic impregnation (PI) which protects the internals of the wire rope from corrosion and crushing. The construction and designation of a steel wire rope is expressed as shown in Figure 11 and this can often be seen on a wire rope test certificate.

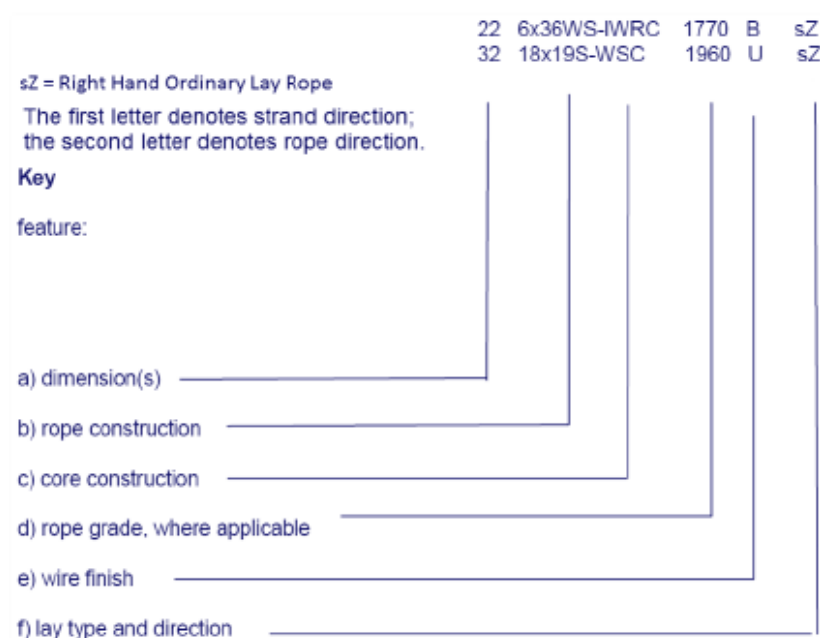


Figure 11 - Wire rope designation description [11]

3.1.2. Failure Mechanisms

There are 8 primary causes of wire rope failure which are:

- **Mechanical wear**
- **Bending fatigue**
- **Corrosion**
- **Tensile overload**
- **Shear**
- **Martensite formation**
- **Heating**
- **Rotation**

Mechanical wear - Mechanical wear within steel wire ropes is the removal of material due to mechanical abrasion. This occurs by wear against sheaves, drums or neighbouring rope wraps. Initially, the rope diameter will reduce at a high rate, however, with the increasing wear, the load bearing surface of the wire rope will increase and the rope diameter reduction will slow correspondingly. Once the rate of diameter reduction slows down, fatigue breaks will appear [20] .

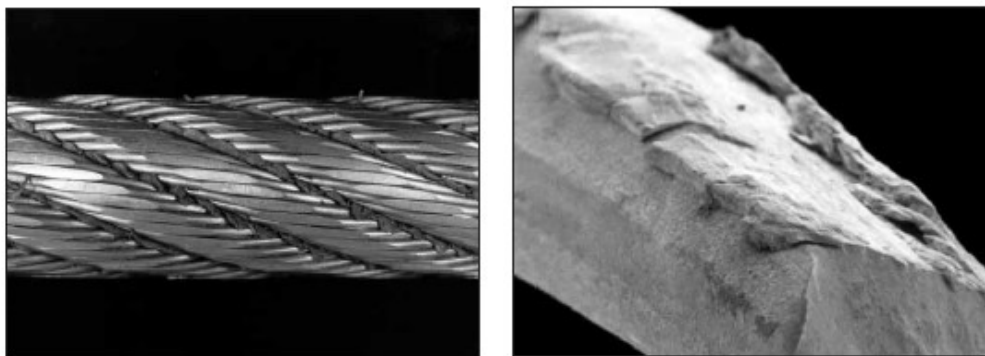


Figure 12 - Mechanical wear on a wire rope and plastic wear on of an outer wire [20]

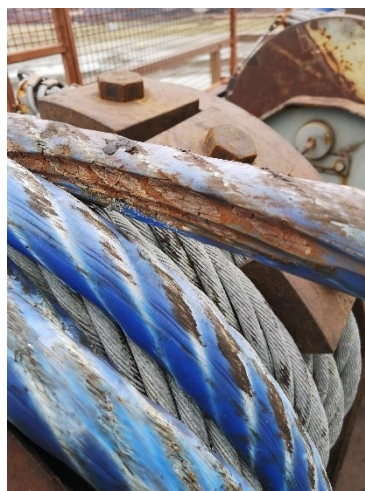


Figure 13 - A wire rope at discard level for mechanical wear on a bulk unloader

Bending fatigue – Rope bending fatigue is caused by the action of the wire rope running over a sheave or rope drum. A fatigue crack normally starts at the points of contact between the outer wires and the sheave or drum surface. Fatigue cracks can also occur at cross over points between individual rope wires where the increasing number of bends finally creates a fracture which is perpendicular to the wire axis. Wear and corrosion will also increase the rate of crack formation and propagation. Remedial actions to fatigue can include increasing the number of wires in a rope and decreasing the diameter of outer wires. However, with increased fatigue resistance, a decrease of wear resistance occurs [20].

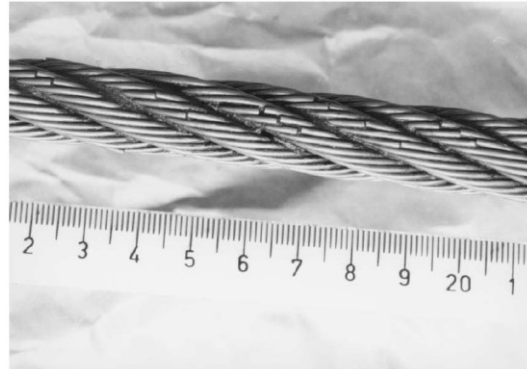


Figure 14 - Large number of fatigue breaks within a 6 strand wire rope [21]

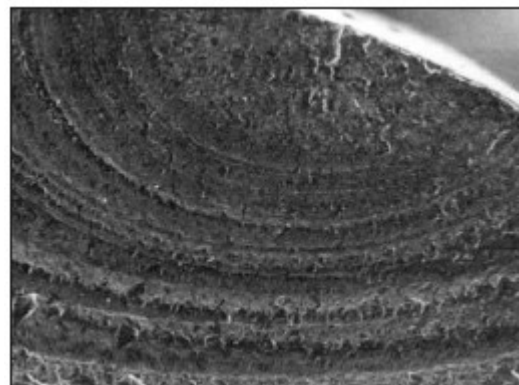


Figure 15 - Fatigue crack radiates from its origin indicated by striations on the surface [20]

Corrosion - As wire ropes often serve in relatively severe working environments such as at Port Talbot steelworks, which has a coastal environment and therefore large amounts of salt in the air, corrosion occurs due to the reactions with environmental mediums. Fracture, wear and corrosion are the main damage types for wire ropes. However, unlike fracture, both wear and corrosion are gradual processes, and they usually interact with each other, inducing early failure of wire ropes. Meanwhile, corrosion can provide conditions for fracture, and accelerates or even directly causes fracture. Wire rope corrosion can be classified into two categories [22]. The first kind is general corrosion due to contact with air, leading to chemical corrosion and electrochemical corrosion. Chemical corrosion occurs when wire rope is exposed in acidic or alkaline environments, and electrochemical corrosion occurs in

humid air environments, as seen in Figure 16. Typically, this type of general corrosion is exhibited within the skip hoist wire ropes due to the high levels of salt within the air.

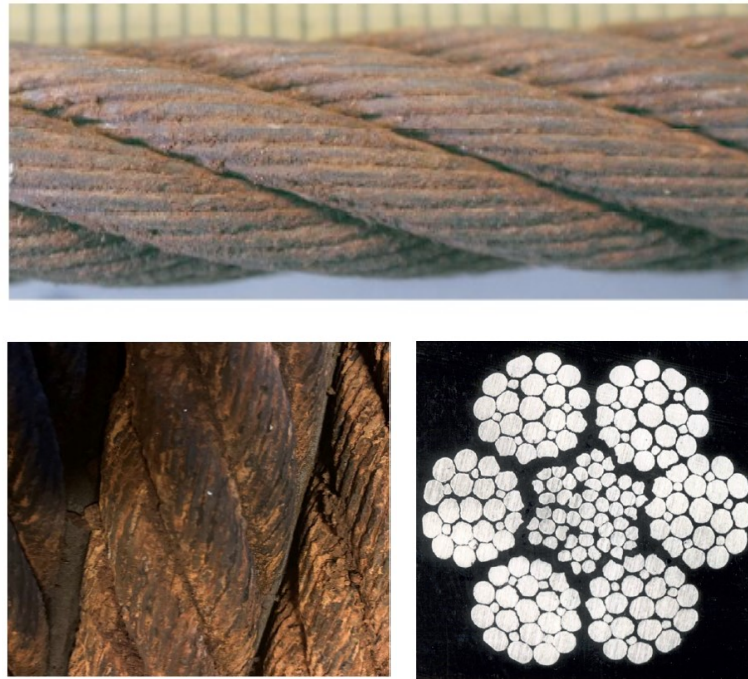


Figure 16 - General external corrosion and internal corrosion examples [16]

The second kind is localised corrosion such as pitting corrosion, seen in Figure 17, by which holes or cavities are produced in the place where the protective coating breaks down. The corrosion pit gradually deepens on the wire rope surface, inducing stress concentration, fatigue crack and decrease of strength and flexibility. The stress concentration will accelerate the propagation of cracks, and finally result in mechanical rupture [23].



Figure 17 - Pitting on individual wires due to loss of galvanic protection [20]

Corrosion can be defined as the deterioration of materials by chemical processes. Of these, the most important by far is electrochemical corrosion of metals, in which the oxidation process $M(\text{metal}) \rightarrow M^+ + e^-$ is facilitated by the presence of a suitable electron acceptor,

sometimes referred to in corrosion science as a depolarizer. Corrosion can be considered as a two-step process where corrosion often begins at a location where the metal is under stress (at a bend or weld) or is isolated from the air (where two pieces of metal are joined or under a loosely-adhering paint film). The metal ions dissolve in the moisture film on the surface and the electrons migrate to another location where they are taken up by a depolarizer. Oxygen is the most common depolarizer; the resulting hydroxide ions react with the Fe^{2+} to form the mixture of hydrous iron oxides known as rust.

A corrosion system can be regarded as a short-circuited electrochemical cell in which the anodic process is something like $\text{Fe(s)} \rightarrow \text{Fe}^{2+}(\text{aq}) + 2\text{e}^-$ and the cathodic steps may involve the reduction of oxygen gas $\text{O}_2 + 2\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^-$ or the reduction of protons $\text{H}^+ + \text{e}^- \rightarrow \frac{1}{2}\text{H}_2(\text{g})$ or the reduction of a metal ion $\text{M}^{2+} + 2\text{e}^- \rightarrow \text{M(s)}$ where M is a metal [24] [25].

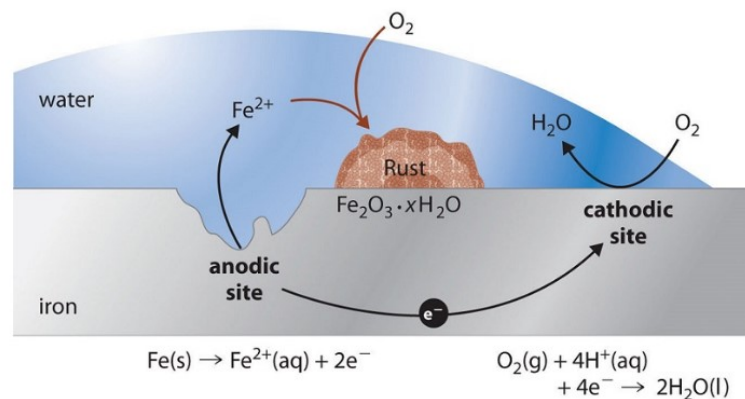


Figure 18 - Schematic diagram of corrosion in iron [24]

Tensile overload - Wire rope is subjected to acceptable safe working loads under normal operating conditions, however, in unfavourable circumstances, this load can be exceeded, therefore overloading a wire ropes minimum breaking load (MBL). In this situation, two phenomena occur. The strands bear against one another causing individual wires to experience shear and when the wires are sheared they no longer support the load. This causes the remaining wires to bear the load, which in turn causes further broken wires and the destruction of the wires speed up. When the strength of the remaining wires cannot bear the load, the rope fails and the wires break with excessive tensile loading. Wires failing from only tensile loading will form a cup and cone type of morphology [26].

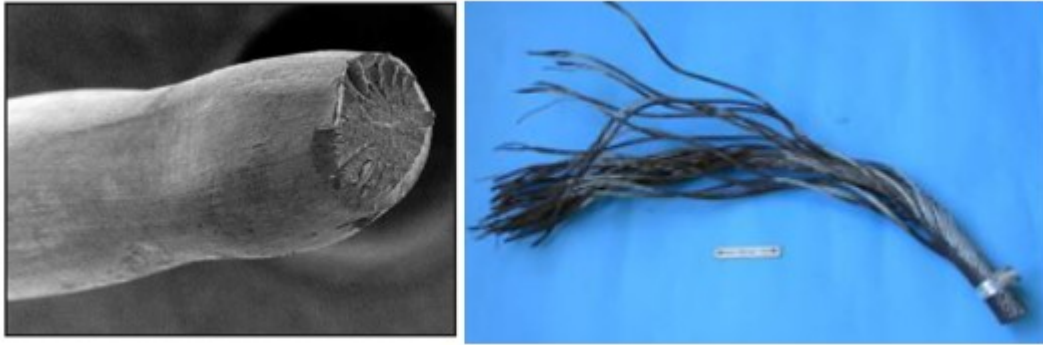


Figure 19 - Cup and cone morphology and catastrophic failure due to overload [20] [27]

Shear - As partially described in the tensile overload failure mechanism, shear failure is due to a high axial load combined with compression of the wire which causes shear breaks. Their break surface is inclined about 45° to the wire axis. The fracture surface is more or less smooth in appearance. Shear failures can also occur by external means, however, this would be covered by mechanical damage [26].

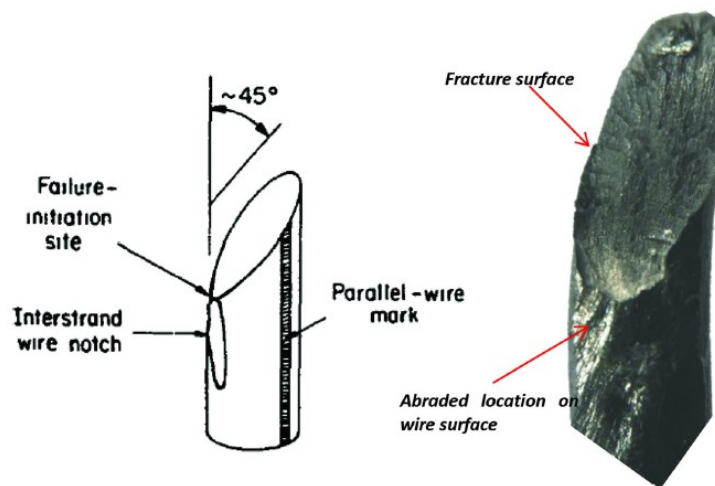


Figure 20 - Typical shear failure starting from an initiation site [28]

Martensite formation – Martensite is a hard and brittle metal structure which is formed when steel is heated up past its transformation point and rapidly cooled. In steel wire ropes, martensite is often found on the crowns of rope wires where they have been dragged over a hard surface, as in Figure 21, due to heat generated from the friction. This thin martensite layer will easily crack when being bent over a sheave, initiating a fatigue crack which will rapidly propagate. Martensite formation is difficult to detect. Even a mounted sample requires etching for the martensite to become visible [20] [29].

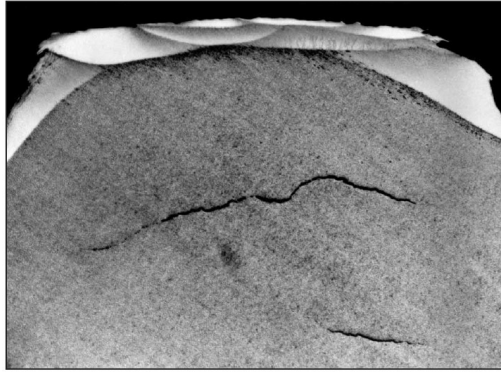


Figure 21 - Martensite formation on a wire rope that has been dragged over steel [20]

Heating - Steel wire rope is a very good conductor of heat. Therefore, zones of a wire rope can work in a very hot environment for a limited time, as long as the heat absorbed by the rope can be conducted away to other, cooler areas of the rope. If, however, the temperature within the rope wires exceeds approximately 300°C, the microstructure of the cold drawn wires will recrystallise, losing about two-thirds of the wire tensile strength in the process. If the energy input is much higher than the rate at which the rope can conduct or dissipate heat, then the wire rope will heat up very quickly. This will happen, for example, when lightning or arcing strikes a rope locally, heating up the wire rope to temperatures where the steel will melt [26] [30] [29]. In the case of the wire ropes considered in this research, there is a low chance the ropes would meet the temperatures discussed, however, weld spatter or burning could occur during maintenance activities.

Rotation – A steel wire rope is made from helical elements and if the rope is twisted in the opening sense, these helixes will be opened up and lengthened. If it is twisted in the closing sense, the helixes will be shortened. These changes in geometry will change the properties of the wire rope and in some cases, considerably. In order to prevent the effect of rotation on a wire rope, both ends must be terminated and correct installation is vital. Twisted rope sections have a tendency to get rid of some of their twist by sharing it with previously non twisted sections of rope and as such, cause the twist to travel through portions of wire rope [20] [31].



Figure 22 - Example of core protrusion due to torsional effects [32]

3.2. Experimental and In Service Wire Rope Testing

There are fundamental differences between experimental testing and in service testing, where the product of each type of activity achieves a different outcome. Experimental testing or investigation is the main source for evaluation of wire rope characteristics and tests have specifically been developed and performed according to each case, minimizing the generalisation aspect. Such cases are static loading, cyclic loading, bending/torsional fatigue or the introduction of external influences which may accelerate degradation of a wire rope [33]. Experimental testing has driven the development of the current standards used today such as 'ISO 4309 Wire ropes — Care and maintenance, inspection and discard' and 'EN 12927 safety requirements for cableway installations designed to carry persons'. For instance, the findings of Woernle (1929), Herbst (1934), Costello (1997) and Raoof (1992) identified the weakening of the rope breaking force is related to the accumulation of wire breaks in critical rope lengths. Based on these findings, the reference rope lengths where the number of wire breaks is important have been standardised [34]. For stranded ropes such as the skip hoist ropes, the reference lengths are normally $L = 30 d$ and $6 d$ which is utilised by the discard criteria in ISO 4309. This type of experimental testing has also helped develop more capable and longer lasting wire ropes for a range of applications.

The in service testing of wire ropes is primarily test data obtained from magnetic wire rope testing (MRT) instruments and can provide accurate quantitative and qualitative estimates of safety-related wire rope parameters such as loss of metallic cross-sectional area (LMA) and localised faults (LF) to provide a more reliable basis for estimating the condition and remaining service life of a rope [35]. Some studies have investigated the use of other non-destructive methods for assessing steel wire ropes, such as ultrasound, eddy current, radiation and optic. However, except for electromagnetic testing, most of these inspection methods have disadvantages such as signals being susceptible to interference, test results that are difficult to record, numerous testing limitations, and expensive equipment. Therefore, electromagnetic testing is currently more widely used [36] [37]. A comparison of other methods for wire rope testing can be seen in Table 3.

Methods	Measurement Principle	Presentation Way	Advantages	Main Disadvantages
Artificial visual method	Inspect the WR surface at a slow speed	Direct analysis and judgment	Simple and direct judgment of surface damage	Time-consuming, and the result is affected by oil pollution and man-made factors
Electromagnetic detection method [7–40]	Measure leakage magnetic flux	Graph line	Qualitative determination of wire breakage, rust, wear and other defects	Difficult to make quantitative measurement and distinguish defects exist at the same time
	Measure main magnetic flux	Graph line	Measure the change of WR metal cross section area	Not suitable for detecting broken wire, especially when the fracture is not obvious
Optical detection method [42–50]	Detect WR surface using camera	Image	Intuitive, and high accuracy of detection	Influenced by environmental factors, data size and machine learning algorithm performance
Ultrasound guided wave method [51–58]	Ultrasound propagates in the medium	Echogram	Detect wire breakage, long distance of single detection	Weak anti-noise ability, cannot reflect the condition of WR in detail
Acoustic emission method [61–72]	Measure the ultrasound emitted by the structural change of steel wire rope	Sound transmission analysis	Detect wire breakage and deformation	Can only be used in the static load part, has low signal-to-noise ratio, high instrument cost and is difficult to measure dynamically.
Eddy current method [73,74]	Eddy current effect	Graph line	Detect wire breakage and rust	Skin effect affects wire breakage detection, and the signal-to-noise ratio is low
Ray method [75,76]	Radiation vertical to the rope with strong X-ray/gamma-ray	Image	Determine wire breakage	Instruments and radiation protection devices are expensive and cannot be continuously measured for long exposure periods

Table 3 - Comparison of wire rope defect detection methods [38]

In service testing is vital to the safety of the wire rope and provides invaluable data to support the safe operation as it is clear that visual examinations have severe limitations such as the introduction of human error and the examiner only having approximately 20% of the metallic cross-section of the rope visible [39].

3.2.1. Experimental testing for research

The predominant test principle used today for bending-fatigue machines is shown in Figure 23. The wire rope to be tested is reeved in a loop over the traction sheave and the test sheave. The traction sheave that moves the rope has a much bigger diameter than the test sheave so that it is always the rope piece running over the test sheave that will break. Therefore, the distance between the sheaves is larger than the rope stroke so that the rope test piece does not move over the traction sheave [34].

Fatigue can be described as a localised damage process of a component produced by cyclic loading. It is the result of the cumulative process consisting of crack initiation, propagation and final fracture of a component. During cyclic loading, localised plastic deformation may occur at the highest stress site. This plastic deformation induces permanent damage to a component and a crack develops. As the component experiences an increasing number of loading cycles, the length of the crack increases. After a certain number of cycles, the crack will cause the component to fail [40]. This can be exhibited as broken wires within a wire rope.

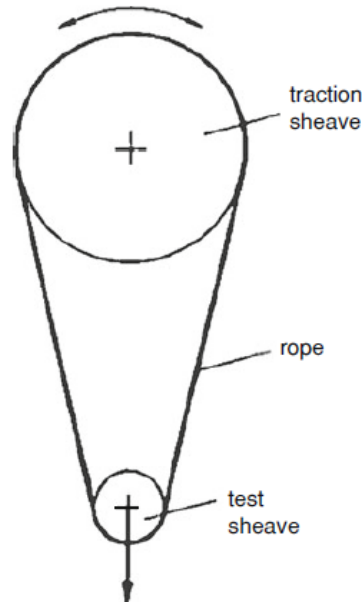


Figure 23 - Arrangement of sheaves for testing the number of simple bending cycles [34]

In addition to the simple bending test, testing can also be carried out through multiple sheaves to create a reverse bending scenario or to replicate adverse environments [41]. This is defined by symbols seen in Figure 24 which are taken from the International

Organisation for the Study of Ropes (OIPEEC) recommendations in the OIPEEC Bulletin 56 1988 [42].

	SIMPLE BENDING	N_{sim}
	straight – bent – straight or bent – straight – bent	$N_{\sim}$
	REVERSE BENDING	N_{rev}
	bent – straight – reverse bent	$N_{\sim}$
	FLUCTUATING TENSION AND BENDING	N_{comb}
	straight, tensile force enlarged – bent – straight, tensile force reduced	$N_{\sim}$

Figure 24 - Symbols for standard loading elements and numbers of bending cycles [42]

Primarily, this section of research focuses on the bending over sheaves (BoS) under tensile load because the skip hoist wire rope system has a similar mode of operation and can be characterised by the fluctuating tension and bending motion as seen in Figure 24. This is also pertinent as previously highlighted within the research, the internal fatigue/wire breaks of the wire rope cannot be assessed purely by visual examination and testing can help identify limits of endurance.

Experimental tests have been performed in the Rope Technology Laboratory of Institute of Mechanical Handling and Logistics, University of Stuttgart, Germany, so as to exhibit effects of tensile load and sheave diameter to the discard fatigue life of steel wire rope running with sheaves. BoS fatigue test bench comprises of an electric motor, test sheave, drive sheave, leverage, rotation speed adjustment button and additional machine elements helping it to run. The motor produces the power on the test machine. The samples are located between drive sheave and test sheave by means of lead casting end connections. Constant tensile load on the test sheave is maintained by leverage and additional weights in order to simulate real working conditions. Thus, rope samples are loaded by constant tensile strain during the test. The bigger sheave is the drive sheave which drives the rope sample at the certain cyclic length and the smaller one is the test sheave. BoS fatigue occurs at the contact length between test sheave and rope which is $30d$ in length (d is diameter of rope in mm) [43]. A depiction of the test machine can be seen in Figure 25.

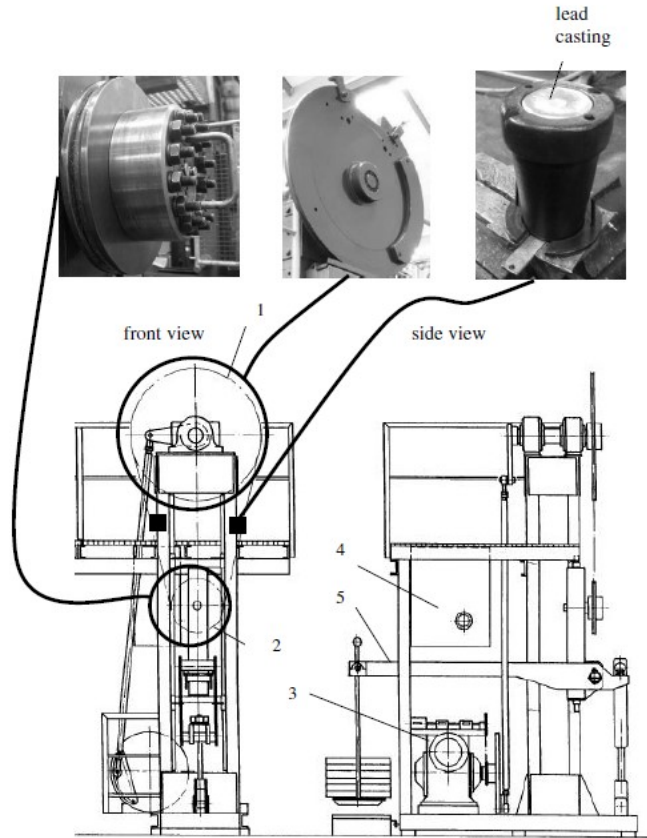


Figure 25 - Bending fatigue test machine [44]

Items indicated in Figure 25:

1. Drive sheave
2. Test sheave
3. Motor
4. Speed adjustment button
5. Weighted leverage

The results that were compiled from the research of Onur and Imrak from the BoS tensile tests clearly show a decrease in fatigue life of a wire rope as the tensile load increases and as the test sheave diameter decreases. The results can be seen in Table 4 and clearly highlight the need for the correct selection of sheave and wire rope combination.

S/d^2 (N.mm ⁻²)	D/d	$N_{A_{theoretical}}$ (cycles)	$N_{A_{test}}$ (cycles)
150	25	54 325	57 702
200	25	39 536	34 986
250	25	30 902	32 608
300	25	25 292	25 672
100	10	21 527	18 503
150	10	11 967	13 060
200	10	7870	12 038
250	10	5701	3983

Table 4 - Theoretical and experimental results for a 6x36 Warrington-Seale wire rope [43]

The type of wire rope tested in the cited literature is of a similar construction to that of the skip hoist, aside from being a smaller diameter. It would be expected that the skip hoist wire rope being a 6x41 IWRC would have a higher fatigue life due to the larger number of wires within its construction. Secondly, the ratio of sheave diameter to wire rope diameter (D/d) is 38 as shown in Equation 5, whereas the literature tests were conducted with a maximum sheave ratio of 25 which would increase the fatigue life furthermore.

$$\frac{D}{d} = \frac{1830}{0.048} = 38.1$$

Where: D = Sheave dia (mm)

d = Wire rope dia (mm)

Equation 5 - Sheave diameter ratio

Thirdly, the tested wire rope was loaded to approximately 20% of the minimum breaking load (MBL) of the wire. Within the skip hoist system, the MBL is 195t with a total loading of 40t, however, this is distributed between two wire ropes hence only loading of 10% MBL. Taking these three points into account, the fatigue life would exponentially increase with the improved operating conditions as exhibited within the skip hoist system and as such, it is possible that fatigue would not be a large concern in the degradation of the wire ropes. For reference, the skip hoist wire ropes would be expected to undergo 345,000 cycles per 2.5 million tonnes use (planned change amount) as seen in Equation 6.

$$\text{Life time hoist cycles} = \text{LOR} \times \text{CPD}$$

$$548 \times 630 = 345,240 \text{ cycles}$$

Where: LOR = Lifetime wire rope (Days)

CPD = Cycles per day (Cycles)

Equation 6 - Total number of cycles before wire rope change

It must be noted that the cited tests are performed within laboratory conditions and would typically exhibit uniform loading with no environmental changes so do not hold true to real world conditions and hence test figures do not directly relate to the system in hand. As there are infinite combinations of wire rope, sheave ratio, load percentage and unloading, the results must be treated as indicative only.

3.2.2. Magnetic rope testing (MRT)

MRT has been used in multiple sectors over the years such as the heavy lifting sector in the 1980s to cableways and more recently the elevator sector in the early 2000s. The technology has drastically improved since earlier utilisation which has led to the introduction to the cableway sector standards and later, the wire rope discard criteria ISO 4309 [45]. Given the critical load bearing nature of steel wire ropes used throughout the world, it has gained increasing attention in guaranteeing that adequate safety margins are met. This is mainly attributed to the large number of human fatalities and economic losses such as the incident on 9th March 2017 where a wire rope of a friction mine hoist at the Mining Company of Heilongjiang Longmei Group suddenly broke during the lifting process causing a cage fall. As a result, 17 people trapped in the cage were killed [38]. Due to the long working periods of wire ropes, the previously discussed defects will inevitably occur which are potentially undetectable during a visual examination and this is where MRT proves an invaluable resource for providing information on the internal and external defects of a wire rope. The principal defects within a wire rope are categorised as being either: Loss of Metallic Area (LMA) – a change in the amount of metallic material at a given position. Loss of metallic area is normally associated with damage such as corrosion, wear or mechanical damage; or Local fault (LF) – a short discontinuity in the wire rope, such as a wire break, cracked wire, welded wire, corrosion pit or inter-strand nicking [46]. Related standards, such as the European norm EN 12927-8, the ISO 4309 and ASTM E1571 [3–5], prescribe the basic detection principles, procedures, relevant instrument, and calibrating method through electromagnetic testing technique in detail [47]. It is also worth noting that ISO 4309 only recognises MRT as the non-destructive detection method for wire ropes which makes MRT the primary choice of defect detection as shown in Table 5.

Mode of deterioration	Assessment method
Number of visible broken wires (including those which are randomly distributed, localized groupings, valley wire breaks and those that are at, or in the vicinity of, the termination)	By counting
Loss of metallic area caused by broken wires	Visual, MRT
Decrease in rope diameter (resulting from external wear/abrasion, internal wear and core deterioration)	By measurement
Loss of metallic area caused by mechanism other than broken wires e.g. corrosion, wear, etc.	Visual, MRT
Fracture of strand(s)	Visual
Corrosion (external, internal and fretting)	Visual, MRT
Deformation	Visual and by measurement (wave only)
Mechanical damage	Visual
Heat damage (including electric arcing)	Visual

Table 5 - ISO 4309 table showing modes of deterioration and assessment methods

3.2.3. How does MRT work and what are the signal differences?

Electromagnetic detection is one of the oldest methods in the non-destructive testing field and has been applied to wire rope detection. In this detection method, there are two different excitation modes including coil excitation and permanent magnet excitation, and the commonly used sensor types are the Hall sensor and the induction coil. The detection principle diagram is shown in Figures 26 and 27.

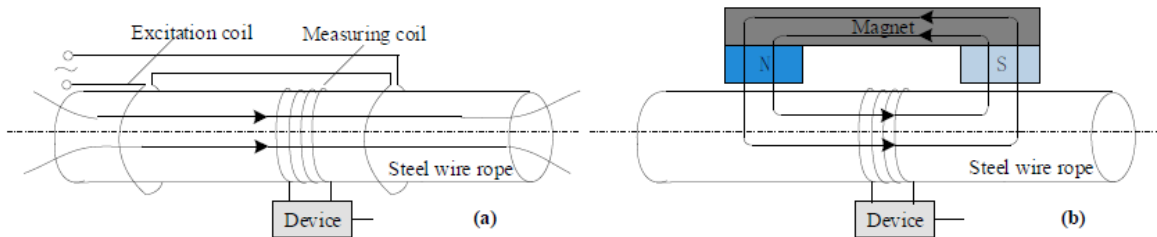


Figure 26 - Coil excitation and permanent magnet methods [38]

The main principle is that after the wire rope is excited by coil or permanent magnet, the surface and internal damages will change the magnetic flux in the wire rope. The signal is then detected by the induction coil or integrated sensor (e.g., Hall sensor and magnetoresistance sensor), and the type or degree of damages can be obtained to a certain extent through further processing and analysis of the signal [48] [49] [50]. Figure 26a is the main magnetic flux detection method based on coil excitation, which adopts the coaxial magnetization method, namely, taking the measured wire rope as the core, and the wire rope segment between the two coils is magnetized by the coil with current. Figure 26b is the main magnetic flux detection method based on permanent magnet excitation, in which the method of inter-pole magnetization is adopted, taking the wire rope as a component of the magnetic circuit, and the induction coil is used to detect the change of magnetic flux inside the wire rope caused by damage.

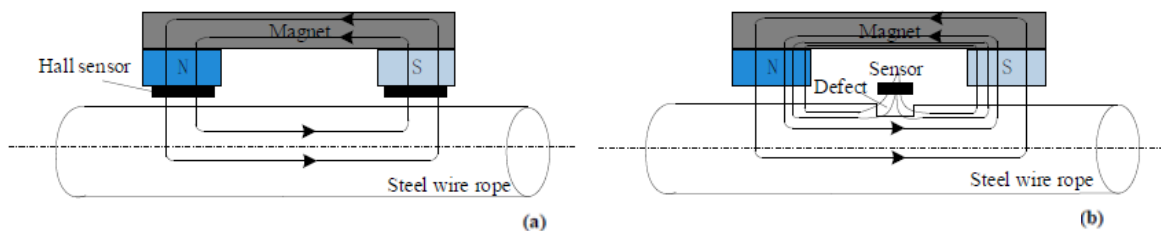


Figure 27 - Return and leakage magnetic flux detection [38]

Figure 27a is a method of return magnetic flux detection based on permanent magnet excitation, whose excitation mode is the same as Figure 26b, but the Hall sensor is used to detect the flux density in the magnetic circuit formed by excitation device, air gap and wire

rope. Figure 27b is leakage magnetic flux detection method based on permanent magnet excitation, whose excitation mode is the same as Figure 27a, however, the difference is that the sensor is used to collect the leakage magnetic field information caused by the damage [38]. For reference, the testing company who are carrying out the work on the skip hoist wire ropes will utilise an AMC Rope 65 with a permanent magnet excitation method equipped with a coil and hall effect sensors (data sheet in Appendix B). This enables the machine to carry out dual signal interpretation which can identify different fault signals (LF & LMA) which identify different failure modes discussed earlier. A comparison of sensors can be seen in Table 6.

Sensor	Advantages	Disadvantages	Applicability
Induction coil	Wide detection range, various types and shapes suitable for many practical applications	Affected by the interference signal from wire strand, electromagnetic and background noise	LF defect detection, range of 1 fT~1 T
Hall element	Sensitive to absolute magnetic field strength, small and reliable, insensitive to the scanning speed	Energy consuming, susceptible to temperature, nonlinear output signal	LMA defect detection, range of 10 μ T~1 T
MR sensor	High accuracy and sensitivity	Additional circuit for signal output is needed, energy consuming, the stability needs to be improved	LF and LMA defect inspection, range of 0.1 nT~0.1T
Magnetic flux gate	High resolution for weak magnetic field, reliable	Energy consuming	LF and LMA defect inspection, range of 10 pT 10mT
SQUID	Highly sensitive to the change of weak magnetic signals	Energy consuming, bulky and expensive	LF and LMA defect, detection range of 0~1mT, frequency range of >1 MHz
PMP	Wide detection range, high sensitivity and accuracy	Susceptible to interference signals from wire strand and electromagnetic environment	LF defect, detection range of 0~1 T

Table 6 - Comparison of different detection sensors [47]

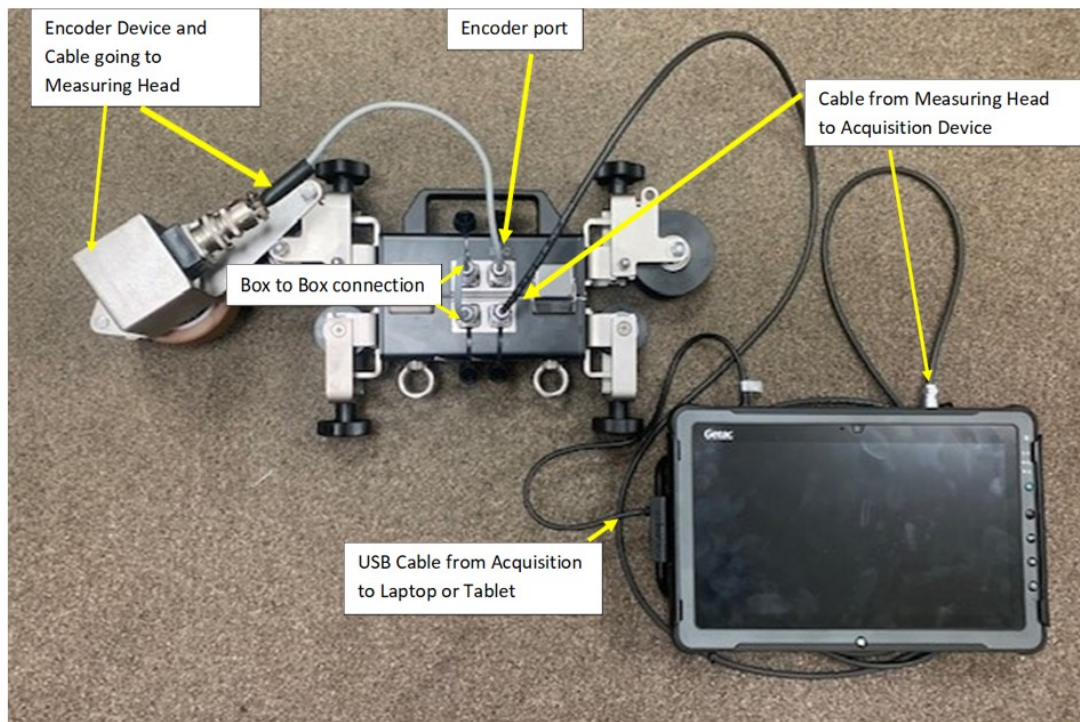


Figure 28 - MRT machine with connected data acquisition unit.

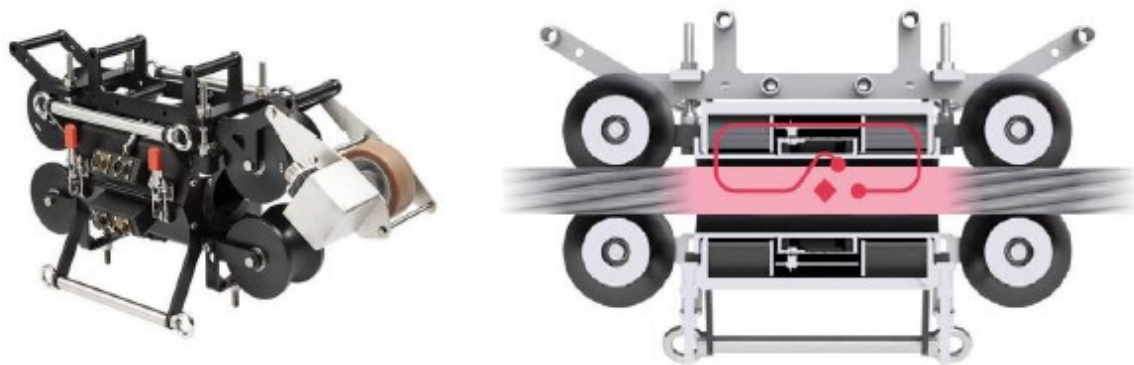


Figure 29 - AMC rope 65 MRT machine [51]

The benefit of utilising permanent magnets over the coil induction system is that the permanent magnet requires no AC or DC power source and the device can be mounted onto the wire rope easier due to the magnetic force, however, permanent magnets can be expensive and the magnetic flux or intensity cannot be altered, unlike the coil induction. This can prove useful when setting up devices for different size and construction of wire ropes to get the best feedback from the machine. There are some limitations to MRT as the machines will not always fit where they are required to work and larger diameter MRT machines can be very heavy and difficult to move. In addition to this, the MRT machine cannot examine in critical areas of the wire rope such as the terminations which endure some of the highest stresses. The MRT is also limited to ferromagnetic materials as the magnetic flux is required

for the interpretation for the signal receiver so this renders MRT redundant for stainless steel wire ropes, for instance.

3.2.4. MRT Feedback Interpretation

The technician carrying out the MRT must ensure that the feedback signals are understood well enough in order to make safe judgements on the wire rope being examined. There are clear distinctions within Annex C of BS EN 12927:2019 which define the inspectors level and their authority to carry out certain aspects of the MRT inspection. For instance, a level 1 inspector must work to written instructions provided by a level 2 MRT inspector. In the case of the wire ropes for the skip hoist, a level 1 inspector would carry out the work and the results are scrutinised and verified by the level 2 inspector. It would be prudent that the customer of the report is required to have some understanding of the feedback as there are clear benefits to being able to understand and explain the report to colleagues within their business.

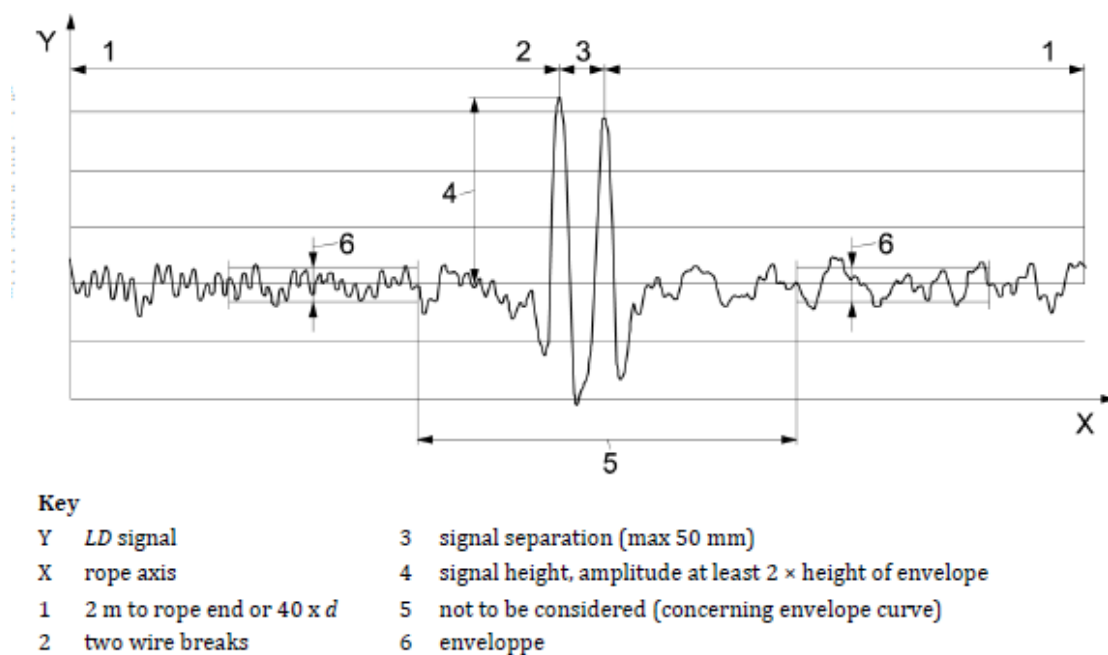


Figure 30 - Two successive wire breaks [52]

As previously discussed, the sensors feedback the data to the acquisition device which supplies a graphical representation of the signals received which can be seen in Figure 24. To interpret the graphical output, it can be said that the envelope is understood as the distance between two parallel lines over a length of 25 times diameter (d) on either side of the wire breaks, where, in all, no more than five peaks of the signature cut the parallel lines. It should be noted that the signature is taken as the reference for assessing the effects of in-service deterioration. The signature reflects the construction of the rope and changes in

magnetic characteristics of the rope among its length, e.g. differences in magnetic permeability. The length of 25 times d on each side of the wire breaks may be demonstrated directly on the graph, using artificial defect, marker or equivalent systems. A region of 0.2 m surrounding the wire break signal is not to be considered for defining the envelope. The amplitudes of each signal of the two wire breaks of the local defect channel shall be at least twice the height of the envelope and two successive wire breaks shall be shown as two separated signal amplitudes, as shown in Figure 30 [52]. Figure 31 shows corrosion which can be identified by the high peak concentration and this means that the rope is deeply corroded.

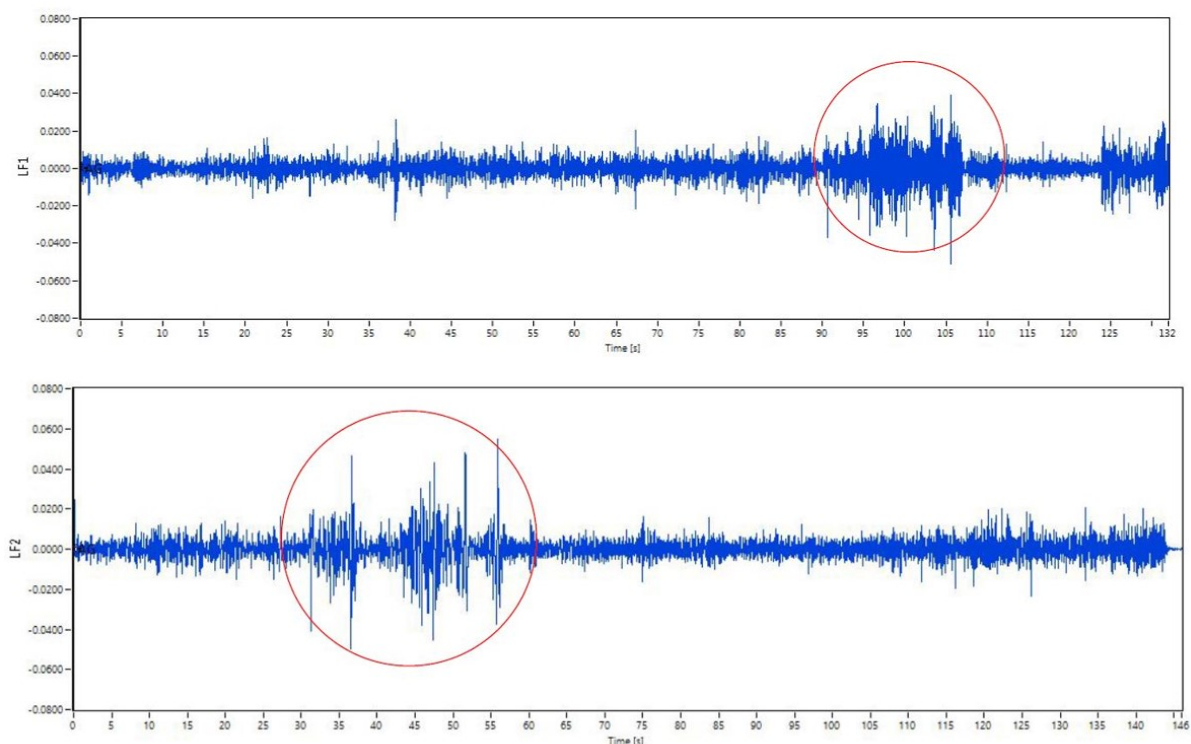


Figure 31 - Two examples of corrosion in a steel wire rope [54]

As previously discussed, the operator interpretation is extremely important as there can be a number of areas for misinterpretation such as coil sensors in use with a steady magnetising flux have the disadvantage that the current generated is proportional to the speed of the rope passing through the measuring head. These changes in speed must be noted by the test technician in order to capture the proportional change. An example of this can be seen in Figure 32. In the same vein, vibrations within the wire rope or machine can also cause a poor trace feedback which again highlights the critical need for accurate notes during inspection [53].

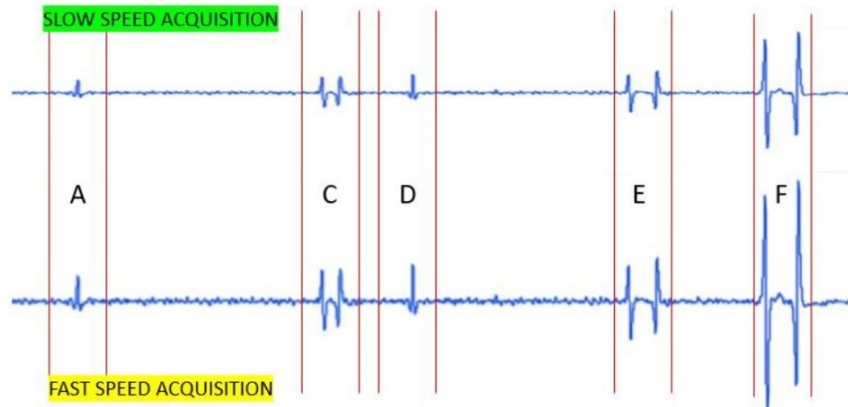


Figure 32 - Speed acquisition related to amplitude [54]

The skip hoist wire ropes will be inspected offline in a workshop at Certex UK, located in Montrose, and as such, a constant speed with minimal vibrations should be observed. However, these considerations should be considered for future testing at the Port Talbot site.

3.3. Conclusions of Research

The research has identified a number of defects that can occur within wire ropes and the varying nature of their appearance depending on wire rope construction, operating conditions and environment. Visual examination (internal and external) and physical measurement has typically been the only technique used to inspect wire ropes and this has its clear limitations in regards to human error and poor judgement, coupled with the examination being predominately external in nature, further limits the examination's effectiveness. It has been identified that out of the 8 primary causes for wire rope failure, two types of defect in particular cannot be identified with a visual examination and this has been seconded by Table 1 of BS 4309. The defects are internal corrosion and internal wire breaks. Taking these points into account, an internal examination is required to identify these defects, in particular where frequency based wire rope changes come at a large cost to a business. From the research carried out and the European and national standards guidance, MRT is the only feasible solution for internal examination of a wire rope without causing further damage by 'opening up' the wire rope. The level of discard criteria as stated in BSEN 4309 has been driven from experimental testing which is still carried out on new wire rope designs today. The discard criteria for the skip hoist wire ropes is 18 or 36 broken wires over $6 \times d$ or $30 \times d$ respectively which ensures that an acceptable level of safety is held within the wire rope and further backs the use of MRT to identify external and internal defects.

MRT does not come without its own challenges, given that the cost of examination is required to be proportional to the cost of a wire rope change in order for the MRT to be feasible. Secondly, MRT cannot give any indication of the distribution of wire breaks around the rope. Since there is a considerable difference between the effects of the same number of breaks concentrated in one strand, as opposed to uniformly distributed, this is an important limitation, but can be easily overcome when visual inspection can complement the NDT. Thirdly, there are a number of MRT machines on the market that have varying advantages and disadvantages and it is imperative that the MRT operator understands the principles of operation of that particular device and is familiar with the limitations of the equipment [53]. A potential limitation of the proposed MRT to be carried out will be the absence of historical data for comparison. It has been identified that MRT becomes even more useful with a historical trace in order to monitor the degradation over a period of time and this should be reflected within the future work of the project.

Overall, the proposal of MRT is backed by in depth and conclusive research and currently remains the primary option for wire rope inspection. In addition, for internal defects, MRT is the only method claimed by regulations EN12927 and ISO4309.

4. Work Carried out

4.1. Wire Rope Removal and Inspection

An early project plan was developed to coincide with the works area for the removal of the wire ropes. However, as previously discussed in section 2.3 of this report, it did have a number of changes regarding dates. The first attempt at the wire rope removal was carried out by the works area team and contractors but was deemed unsuccessful in view of this project. The reason being was the wire ropes were cut in into short sections which made the wire rope unusable for the MRT inspection which put the project in a difficult situation. Further planning then identified a second opportunity for a set of wire ropes that were approaching their life cycle change out of 2.5 million tonnes. The second attempt at removal of the wire ropes on blast furnace 5 was successful and the wire ropes were able to be spooled and sent away to Certex for inspection. A safe working procedure (SWP) of removal can be seen in Appendix C. A new working method was suggested with the use of a spooler over other means, however, due to time constraints, this was unused for the removal despite being available. The spoolers, however, were utilised for the reeling the wire rope onto the drum for transportation.



Figure 33 - Wire ropes packed for shipping

For reference, the dimensions of the reels are 1.3m (h) x 1.3m (w). After shipping the wire ropes to the Certex depot located in Montrose, Scotland, the wire ropes were then cleaned utilising a mechanical 'Viper' device as seen in Figure 34 and set up for the MRT inspection.

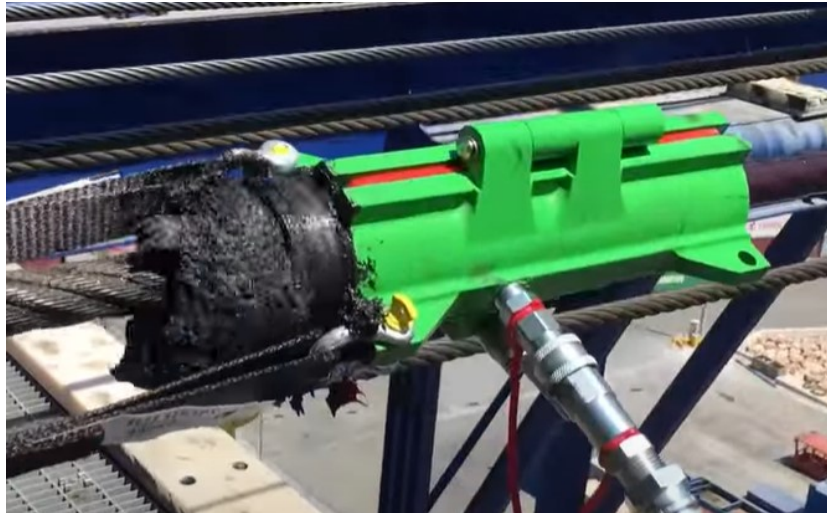


Figure 34 - Viper wire rope cleaner [55]

The MRT inspection was carried out by a level one inspector and the results were subsequently verified by a level two inspector with a larger range and duration of experience. Once the reports were approved and submitted to Tata Steel, the results were then scrutinised to ascertain the forward direction of the project.



Figure 35 - MRT testing at the Certex facility

4.2. Skip Hoist Maintenance Plan Investigation

During the preliminary walkthroughs of the skip system, it became apparent that there was a potential issue within the maintenance routines due to the defects identified such as a collapsed bearing, over/under greasing and lack of cleaning. This prompted a maintenance plan investigation as to which the computerised maintenance management system (SAP) was explored. The searches primarily focused on what maintenance plans were in the system, the completion rate and what data supported these activities such as working instructions, critical measurement points and breakdowns. From the data scrutinised, it was not evident that there was a catastrophic failure due to the wire ropes alone and this further backed the hypothesis of the life extension project. In order to be able to assess the data more accurately, the data had to be filtered and it was decided that utilising the superior functional location (the system as a whole rather than individual components) and focusing on the winch system alone was the most appropriate action i.e. no holding hoppers, electrical drives etc. This reduced the number of plans for scrutiny from 34 to 10. During this scrutiny it was clear that the work instructions provided were not to the required standard and had no measurement points for accurately tracking potential degradation. There were also no clear descriptive areas (such as heat maps/drawings) to support the inspection as can be seen in Figure 35.

NO	EQUIPMENT	CHECK	COND
1	MID BRIDGE SHEAVES	VISUALLY INSPECT RIM PROFILE AND SHEAVE PROFILE FOR DISTORTION.	
2		VISUALLY INSPECT SHEAVE PROFILE DURING REVOLUTION LOOKING FOR ANY SIDE TO SIDE MOVEMENT.	
3		LISTEN FOR ANY UNUSUAL NOISES.	
4		VISUALLY INSPECT KEEP PLATES, CAPS AND COVER PLATES FOR SECURITY AND CORRECT NUMBER OF BOLTS PRESENT.	
5		CHECK PEDESTAL BEARINGS FOR BOLT SECURITY	
6		CHECK SHEAVES AND BEARINGS FOR EVIDENCE OF LUBRICATION	
7		CHECK BEARING END SEALS	
8		CHECK SHEAVE SUPPORT STRUCTURE FOR INTEGRITY AND CONDITION	
9		CHECK ALL GUARDING FOR CONDITION AND INTEGRITY	
COMMENTS			

1. ENSURE ALL NORMAL SAFETY PRECAUTIONS ARE TAKEN WHEN CARRYING OUT ALL JOB REQUESTS.
2. INSPECT/REPAIR ANY PLANT THAT IS ACCESSIBLE AND SAFE TO WORK ON.
3. INSPECT/REPORT ANY PLANT FAULT THAT REQUIRES ENGINEERING PREPARATION WORK.
4. ENSURE ALL ITEMS ARE SOUND, SECURE AND ARE RECEIVING LUBRICATION WHERE NECESSARY.

Figure 36 - Work instructions from skip hoist maintenance plans

In addition to this, critical points were being missed such as adequate lubrication of the wire ropes and monitoring not being carried out and it was highlighted that the wire ropes and

sheaves were being steam cleaned on a periodic basis. This method of cleaning can have an impact on the lubrication of the wire rope and can cause early signs of corrosion.



Figure 37 - Evidence of poor cleaning/lubrication

During this scrutinisation, it also became clear that the blast furnace team were requiring to alter the wire ropes at frequent intervals (every 2-3 months) due to elongation. The data gathered so far does not suggest that elongation is the case, however, this should be explored in further work as it does not fit the scope of this project. Lastly, the completion rates for some tasks were as low as 20% with a majority of them not being completed within a timely manner. This could clearly be a detrimental factor when looking to extend the life of the wire ropes.

4.3. Cost Analysis

4.3.1. Blast Furnace Downtime

One of the larger costs for Tata Steel Port Talbot is an unintentional stop of the blast furnaces, despite the blast furnace not being the largest bottle neck in the steel making process. This is primarily due to the unit having the capability to recoup lost tonnage over a period of time, however, this still does have a large implication on costs. Blast furnace production rates vary depending on numerous factors, but if an average hourly production rate of 250 tonnes per hour is utilised, a calculation can be carried out to find out the fixed cost recovery rate to bring the blast furnace back online. A basic breakdown of blast furnace downtime costs can be seen in Equation 7.

$$\text{Blast Furnace downtime} = \text{TPH} \times \text{FCR}$$

$$\text{Blast Furnace downtime} = 250 \times \text{£}50 = \text{£}12,500 \text{ per hour}$$

Where: TPH = Tonnes per hour (metric tonnes)

FCR = Fixed cost recovery rate (£)

Equation 7 - Blast furnace recovery costs

This calculation is excluding other incorporated costs such as an increased use of raw coke which lowers the rate of gas production within the furnace, which in turn affects other business units as blast furnace gas is utilised in other areas such as the energy power plant, granulated coal injection and the coke ovens. This causes the processes to require the use of natural gas which comes at a far larger cost than recovery.

For reference, for every 200,000m³ of air used to fuel the blast furnace production, 300,000m³ of blast furnace gas is produced.

Overall, the downtime per hour for the blast furnace can cost in the region of £30,000 - £50,000 per hour.

Note: Figures are approximate due to the number of variations that can occur such as cost of natural gas, cost and amount of raw material used/wasted, production speed and furnace variation.

4.3.2. Wire Rope Replacement

The consideration for the cost of the wire rope replacement is a critical cost to scrutinise. This cost can be added to the final cumulative figure for an unplanned outage and also considered against the cost of MRT for feasibility of ongoing inspections.

Pricing Matrix												
Reference No.	KSS/8112											
Tata Steel Ref												
Job Description	Blast Furnaces - Fixed Price Contract - Nos. 4 & 5 Blast Furnaces - Change the Skip Hoist Ropes											
Cost Grand Total (£)	£20,812.44											

Overview	
Design	£0.00
Labour	£8,069.92
Plant & Equip.	£1,673.76
Equip. Hired	£685.00
Materials	£9,927.76
Off Site	£0.00
Consumables	£456.00
Travel & Accom	£0.00

Please click on the Tata logo for HELP at any time -->


Labour												
			Rate (see below)									
	Grade	Number of Men	A	Hours	B	Hours	C	Hours	D	Hours	E	Hours
Pre - Job	Manager	2	£33.32	4	£42.45		£43.30		£53.86		£30.05	
	Supervisor	1	£30.45	8	£38.66		£39.52		£49.23		£27.94	
	Charge Hand		£28.98		£36.50		£37.35		£46.82		£27.15	
	Advanced Craft	4	£27.91	8	£35.51		£36.36		£45.48		£26.47	
Site Work	Supervisor	1	£30.45	8	£38.66	8	£39.52		£49.23		£27.94	
	Coded Welder	1	£28.98	8	£36.50	8	£37.35		£46.82		£27.15	
	Advanced Craft	7	£27.91	8	£35.51	8	£36.36		£45.48		£26.47	
	Supervisor		£30.45		£38.66		£39.52		£49.23		£27.94	
	Coded Welder		£28.98		£36.50		£37.35		£46.82		£27.15	
	Advanced Craft		£27.91		£35.51		£36.36		£45.48		£26.47	
Post Job / Commissioning	Supervisor	1	£30.45	8	£38.66		£39.52		£49.23		£27.94	
	Coded Welder	1	£28.98	8	£36.50		£37.35		£46.82		£27.15	
	Advanced Craft	7	£27.91	8	£35.51		£36.36		£45.48		£26.47	
											Total Cost	£8,069.92

A: Normal Time 8 hours Monday to Thursday, 6 hours on Friday
B: Midweek Overtime After normal shift until Midnight
C: Weekend Overtime First 4 hours on Saturday Morning
D: Weekend Overtime After first 4 hours on Saturday and until 8am on Monday
E: Lie in Shift 8 hours break after nightshift working

Plant & Equipment				
Item	Description	No. of Hrs	Cost per hr	Total
1	Burning Equipment	32	£4.08	£130.56
2	Welding Equipment (including Generator)	24	£5.11	£122.64
3	Site Transport	64	£6.17	£394.88
4	110 Volt Equipment	48	£1.26	£60.48
5	Telehandler	32	£13.06	£417.92
6	Hiab Lorry	32	£8.77	£280.64
7	Safety Harnesses	144	£1.00	£144.00
8	Compressor	24	£5.11	£122.64
				Total Cost £1,673.76

Equipment Hired - Please amend hire period as appropriate e.g. hrs, days, weeks				
Item	Description	No. of weeks	Cost per week	Total
1	Lifting Tackle	1	£300.00	£300.00
2	Gas Monitors	9	£25.00	£225.00
3	Radios	1	£80.00	£80.00
4	Impact Gun	1	£80.00	£80.00
5				£0.00
				Total Cost £685.00

Materials				
Item	Description	Cost (exc mark up)	Mark-up(%)	Value of mark up
1	2 x Skip hoise wire ropes	£9,927.76		
				Total Cost £9,927.76

Consumables				
Item	Description	Cost (exc mark up)	Mark-up(%)	Value of mark up
1	P.P.E	£256.00		
2	Consumables	£200.00	5%	
				Total Cost £456.00

Table 7 - Wire rope change cost

4.3.3. MRT Costs

The cost of the MRT had a number of auxiliary requirements such as the transport to the Certex depot and the requirement of a spooling machine. These costs would not usually be associated with on-site testing which has caused a clear increase in the total amount. Going forward, further costs could be mitigated by purchasing a spooler and removal of the shipping costs. It should be noted though that there may be some minor extra expenses such as travel time and overnight accommodation for the MRT engineer.

Item	Cost
Wire rope spooler	
<i>7 day Hire</i>	£999.95
<i>Delivery and collection</i>	£1911.10
<i>Transit rate each way</i>	£222.20
MRT and cleaning of wire ropes	£3159.00
Shipping to Certex	£2992.50
Total	£9,284.75

Table 8 - MRT cost breakdown

4.3.4. Total Cost Discussion

As can be seen from section 4.3 of the project, the total cost for the wire rope change and MRT for the project came to a total of £30,097.19. The added costs came due to the MRT which is part of the trial for the project and was required to be spooled and sent away for the testing. It is often seen in trial projects that costs are increased, however, these should be paid back if the project comes to fruition. For instance, if the results support the hypothesis of the project and the wire rope life was extended by 6 months, (approx. 830,000t of material) then the costs could clearly be deferred lowering annual spend and other maintenance activities could take place. These cost assumptions are also carried out on a planned outage so there would be another increase in the removal cost for a breakdown scenario. In the event of a breakdown scenario, the blast furnace operational costs can also be included which would exacerbate these costs exponentially, given that the previously calculated downtime costs in the region of £30-50k per hour. For reference, a skip hoist wire rope takes approximately 16 hours to change.

4.4. Return on Investment

It's clear that for the aim and objectives of the project to be successful, the suggestions provided are required to be feasible for long term implementation. The following calculations take into account the current frequency of wire rope change and the potential suggestion of online testing on the skip hoist ropes at set periods. This is considered against the initial investment for the testing phase.

The total cost of the experimental MRT inspection for the project was £9284.75 and this included the hire of a spooler and shipping. All other associated costs can be disregarded as they occur during a standard wire rope change. Tables 9 and 10 consider the costs for the current change out frequency and suggested extension. The following cost approximations have been used: Blast furnace downtime at £30,000 per hour and MRT cost at £3500 per test, requiring 8 hours downtime.

Current run rates (2.5 Mt)	
Wire rope change	£20,812.44
16 hours downtime	£480,000
Total	£500,812.44

Table 9 - Costs for wire rope changes at 2.5MT

Table 10 considers the costs if online testing was to take place at 1 year and 1.5 years respectively with a view to extending the life of the wires by 830kT

Change extended by 6 months (830kT)	
2 tests at 1 year and 1.5 years	£7000
8 hours per test BF downtime (approx.)	£480,000
Total	£487,000

Table 10 - Costs for online testing at 2 intervals

Now utilising the cost of MRT, the current change costs and the proposed solution, a return on investment calculation can take place.

$$ROI = \frac{\text{Net profit}}{\text{Cost of investment}} \times 100\%$$

Equation 8 - Return on investment

$$ROI = \frac{£13,812.44}{£9,284.75} \times 100\% = 149\%$$

As can be seen with the proposed strategy, there are clear cost saving benefits to implementing a condition monitoring strategy over a frequency based program. It is also worth noting that this calculation only takes into account one cycle of a rope change. After three cycles, the profit grows exponentially due to one less theoretical wire rope change and the requirement for blast furnace downtime.

5. Results

It can be seen in Figure 38 that the whole test data for Rope 1 and Rope 2 show some correlation in the locations of the defects and this is to be expected given the wire ropes are operated as a pair and were replaced as a pair. The results indicated a number of 'potential' defects throughout the 160m lengths of the tested wire ropes, however, given the nature of the MRT inspection which is largely qualitative and potentially subjective in nature, this is to be expected and certain aspects of the feedback within the report may not meet the discard criteria that falls under ISO4309.

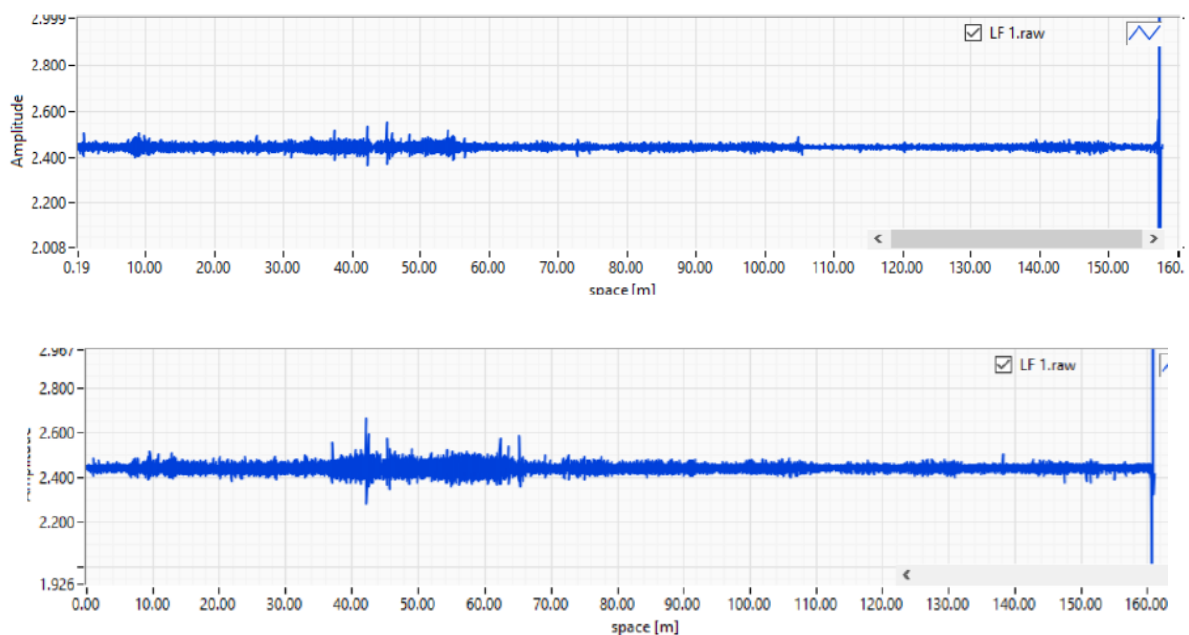


Figure 38 - Full test data for Rope 1 and Rope 2

This can be proven where within wire rope one at 42m – 43m, it was identified that there were multiple wire breaks, however, in the supporting picture where the wire rope was disassembled for inspection, it is not immediately apparent that the broken wires would meet the discard which can be seen in Figures 39 and 40.

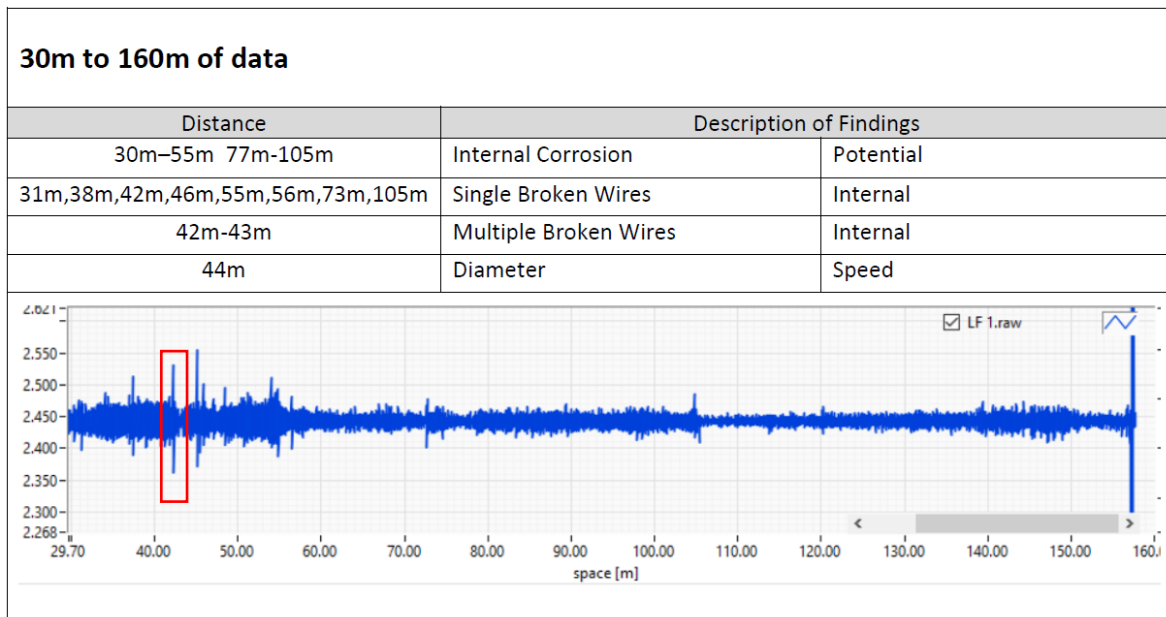


Figure 39 - Multiple broken wires identified at 42m



Figure 40 - Destructive testing of the wire rope at 42m

As stipulated within ISO4309, this type of 6x41 lang lay IWRC rope is classified as a RCN11 which stipulates that for over 6 or 30 x diameter of the wire rope length, the permissible number of broken wires is 10 and 20 respectively. For simplicity, in 0.276m there can be 10 broken wires and in 1.38m, there can be 20 broken wires. Similarly, with wire rope two at 42m, there was the identification of internal broken wires. However, at this point the wire was not destructed to identify the issues. Another point to note regarding the multiple broken wires at 42m was the correlation between Rope 1 and Rope 2 where both wire ropes had identical defects at the same area. It is understood that the wire ropes both operate in the same cyclic manner, however, to identify multiple broken wires in a set of wire ropes at

exactly the same point is unlikely. It is of the opinion that this damage was caused by external factors such as the removal procedure or crushing of the ropes.

It has also been noted in both wires that internal corrosion has played a role in the suggestion to discard, and, as per ISO4309, any internal corrosion would warrant an immediate discard. Upon opening both wire ropes, it was clear that the corrosion was present but not at an advanced stage as can be seen in Figure 41.



Figure 41 - Wire rope one and two showing internal corrosion at 55m and 53m

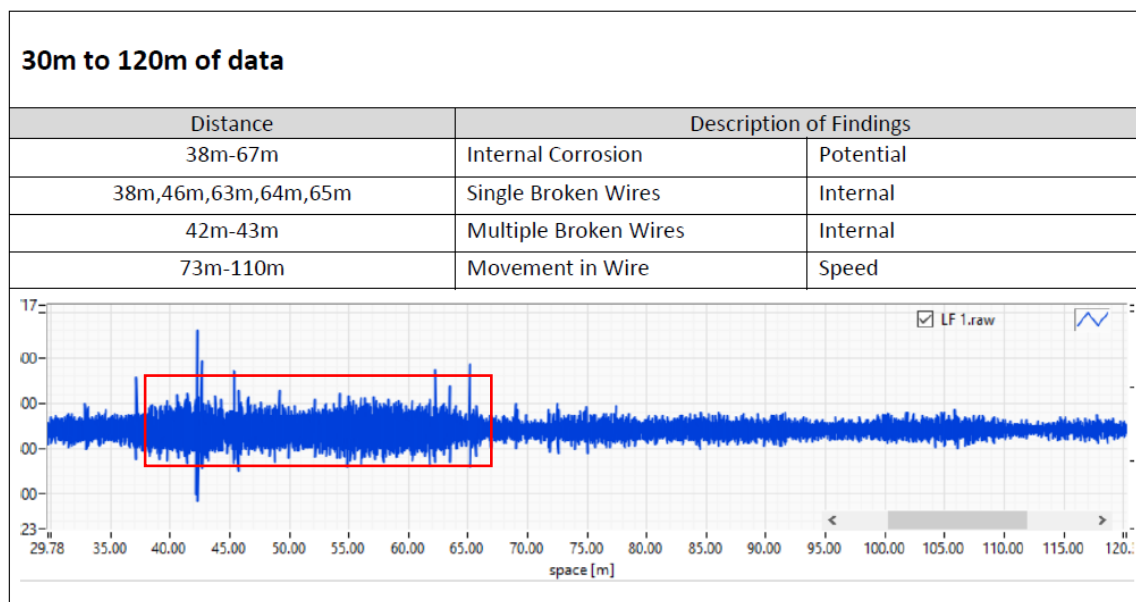


Figure 42 - Corrosion indication between 38m - 67m

It should be noted that the wires were subject to being left in poor conditions after the removal from the skip hoist system and this could have played a contributory factor to this degradation. As with the broken wires, the portion of wire that has multiple broken wires was potentially subjected to continual compression from mobile plant. It is clear that the MRT

results do tie in with the physical investigative destruction of the wire rope and as an indication tool, it has proven very useful. However, without baseline measurements, it is difficult to ascertain the levels of discard within the wire rope. For reference, a full report of the results can be seen in Appendix E.

6. Discussions and Conclusions

The first notion that the skip hoist wire rope lifecycle may be extended was due to the lack of evidence to support the replacement strategy at 2.5 millions tonnes because after each thorough examination by the subject matter experts, there was minimal degradation through broken wires, corrosion or increase/decrease in diameter. However, it should be understood that this was a visual/measurement inspection with no internal examination. It was at this point where the suggestion of MRT could be considered for extending the frequency of replacement. There was also little historical evidence as to why the decision was made to change the wire ropes at this tonnage and after consultation with the wire rope manufacturer, the suggestion was made that the discard criteria in ISO4309 should be adhered to or historic data which does not appear to be available. Email communications can be seen in Appendix D. In the initial discussions that took place regarding the life extension of the skip hoist wire ropes, it was proposed that MRT inspection was to be carried out on the hoist itself which would have had clear benefits such as lower initial costs and a more accurate reflection of the current condition of the wire ropes, however, it was deemed that this was a large risk to the business as if the reports were unfavourable, it would cause large financial implications for the business, hence the choice to remove the wire ropes and send them for MRT at a test facility. The primary area of interest was clearly not the external wire breaks given the historical data of the thorough examination reports but the internal fatigue breaks and corrosion which MRT has been proven to identify, albeit qualitatively. The wire rope structure being of a 6x41 compacted wire rope lends itself to bending fatigue and in addition, the wire rope being of lang lay which lowers internal stresses on the individual wires, did ease concerns around internal fatigue breaks.

During the removal of the wire ropes, it was unfortunate that the suggested method of the spooler was not adopted and it is believed that this has caused some spurious results that should be questioned. In addition to this, the wire ropes were left for approximately two weeks in water with 83te Caterpillar 773 trucks crossing them daily, which is believed to have contributed to the corrosion and certain areas of multiple broken wires as highlighted within the results discussion. Keeping this in mind, the results did come back relatively favourably as the primary concern was internal corrosion which was highlighted by discussions with the MRT tester. This failure mode can be mitigated with the correct wire rope care and maintenance routines such as correct cleaning and lubrication application. Further to support the suggestion that the storage possibly contributed to the corrosion is that it would be expected to see uniform corrosion throughout the wires and not in sections as identified in the results. The wire rope is also of a plastic impregnated construction which

would usually protect the wire ropes from any internal corrosion. It is quite clear that the interpretation of the results has an amount of subjectivity to it, however, it is proven that the technology can identify internal defects which was confirmed by the destructive testing photos. Another point to note is that maintenance plans have been identified to be missing key work instructions and vital maintenance tasks that would further benefit the fatigue life of the wire ropes. The lack of quality work instructions could be contributing to potential poor execution of maintenance tasks which, when coupled with the low completion rate of maintenance plans, could lead to early degradation.

From the evidence gathered, it is believed that with the right care and maintenance, the wire rope life could be extended gradually through a condition monitoring program which includes the use of visual inspection alongside MRT. To be confident of the wire rope safety, it would be suggested that MRT is carried out on an 8 or 12 month frequency to initially ascertain a baseline report which can be used to track the degradation observed in the feedback. This would build confidence with the results and should be done alongside the regular maintenance and inspection.

In summary, MRT is a useful technology for the identification of internal defects and the only suggested inspection technique for internal defects claimed by international standards. However, it is very difficult to interpret and corroborate results from a singular inspection and a baseline result would be better suited for comparison. It is believed that the wire ropes are not experiencing fatigue related wire breaks, and, as discussed previously, it is of the opinion that the wire rope life could be extended with the correct program in place. This is further backed by the return on investment calculations where the company could see maintenance activities better allocated during plan stop periods.

7. Recommended Further Work

7.1. Short Term

1. The options of wire rope grease / oil should be explored to combat the occurrence of corrosion as identified within the results should be carried out taking into account the environmental conditions.
2. Maintenance plans should be further improved with clear work instructions and a strategic maintenance program such as reliability centred maintenance (RCM) implemented.
3. Wire rope removal procedure should be reviewed to include any recommendations from the wire rope manufacturer / specialist.
4. Information from this dissertation should be disseminated through the monthly crane maintenance forum to ensure visibility of the research and use of MRT.
5. Present finding to the Director of Engineering for further investigation.

7.2. Long Term

1. For MRT inspection to be implemented at Tata Steel Port Talbot, it is recommended that online testing/monitoring should be carried out on the skip hoist system to gain a more accurate set of results to support the hypothesis of the life extension. This data should be tracked to monitor degradation over the lifecycle.
2. Investigate the feasibility for a remote continuous monitoring system as discussed in Appendix D.
3. Explore as to why the wire ropes require periodic adjustments – wire rope stretch or system adjustment.

Appendices

A – Skip Hoist Wire Rope Certificates

As discussed in section 1.2. a copy of the wire rope certificates can be seen in appendix pages IV – V.



EC Declaration of Conformity

This certificate meets the requirements of the Machinery Directive 2006/42/EC Annex II

Name & Address of Manufacturer or Authorised Representative:	Customer's Delivery Address:
Certex UK Unit C1 Harworth Industrial Estate Bryans Close Harworth DN11 8RY	Tata Steel Abbey General Stores Port Talbot Works Port talbot Mark Thomas Mon-Thur 0700-1400 Fri 0700-1200 SA13 2NG
Certex Order No: 1366463-1 / 1	Customer Order No: 4512533898

The person authorised to compile the technical file is the local Manager named below.

Quantity	Serial Number/s	Description of Equipment and Components used	WLL*
4 PC	66463-1/1/ (1-4)	03A0210 CORUS 5402285 L=195M 48MM DF6 BRISTAR BT RHL 48mm DYF 6 BRISTAR BT RHL Pin Centre to Outside End - Matched Pair Inboard End Solid Thimble Drilled With Hole 75mm-75.07mm 5 Tuck Splice. Other end F&T Double Open Cable Sock to be Att to F&T End & Reel Thimble Thickness not to exceed 70mm Test Cert With Goods. Tag Attached To Goods Tag To Show Corus Stock No, Order No, Test Cert No, Dia & Length	



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Certex Order No: 1366463-1 / 1	Customer Order No: 4512533898

The person authorised to compile the technical file is the local Manager named below.

* Where a Working Load Limit is shown above, the working load limit has been calculated to meet the requirements of the relevant harmonised standard. For steel wire rope assemblies, other than slings, it is the responsibility of the manufacturer or designer of the installation, equipment or appliance to establish the correct coefficient of utilisation, safety factor, factor of safety or design factor. If the assembly is to be used at a different coefficient of utilisation to that shown in the harmonised standard, it should be re-rated by the competent person. Steel wire rope assemblies, other than slings will be stamped or labelled with a CE mark and traceability code only. To avoid confusion, the Working Load Limit will not be shown on the product.

Harmonised or Other Technical Standards & Specifications Used

Declaration.

I declare that the above equipment fulfils all the relevant provisions of this Directive and the relevant Harmonised or other Technical Standards & Specifications named above.

The identity and signature of the person empowered to draw up the declaration on behalf of the manufacturer or his authorised representative:

Printed Name	Signature	Place of Declaration	Date of Declaration
Roy Henderson		HARWORTH	24/11/22

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B – AMC Rope 65 Data Sheet

In section 3.2.3. a discussion took place regarding the types of data acquisition devices. The specification for the machine used on the wire rope test can be seen in appendix page VII.

ROPE 65



AMC ROPE 65 device, able to perform Non-Destructive-Tests on wire ropes with diameter ranging from 20 to 65 mm. The device works on ferromagnetic ropes.

The system allows to measure the LF & LMA Signal, detecting internal and external flaws, such as broken wires, corrosions, wear and fretting fatigue.

Main characteristics of our device are:

- device internal Rope Centering System (mechanically guided by wheels) that improves signal quality and friction reduction in the bushings;
- presence of a fully integrated Encoder system that localizes the flaw.

WEIGHT	32 kg
DIMENSIONS	75 x 55 x 45 cm
IP	66
NUMBER OF ROPES CHECKED AT THE SAME TIME	1
ENCODER & CENTERING SYSTEM	Included
CERTIFIABLE UNDER THE EN12927	Yes

SENSORS KIT

STANDARD RANGE	65 – 40 mm
MIN ROPE DIAMETER	20 mm
NUMBER OF BUSHING KIT	2

INSTRUMENT CHARACTERISTICS

FIELD SOURCE	Permanent magnets (NdFeB)
SENSOR TYPE	Colls; Hall Effect Sensors
SIGNAL TYPE	LF; LMA (on request)
SIGNAL ACCURACY	In accordance with EN12927
TEST SPEED MAX 0,02 – 10 m/s	Standard range, speed higher than 8 m/s on request

Figure A - AMC data sheet [56]

C – SWP for Wire Rope Change

As indicated in section 1.3. it was the responsibility of King Site Services to carry out the rope change as per the procedure in appendix pages XI - XIV.

CHANGE SKIP HOIST ROPES BF4 & BF5

Workscope

To provide Competent Supervision, Skilled Labour, Plant, Tools, Tackle, P.P.E., Transport and Materials to carry out the Changing of BF4/BF5 Skip Hoist Ropes.

Anchoring Skip Car

- Supply JMS
- Sign on Isolations & PBS/ATWc
- Transport materials and equipment
- Tata to position Skip Car on Skip Bridge near anchorage point.
- Tata Electrical Engineering Department to isolate Skip Hoist drive.
- Using wire rope slings and shackles, attach the Skip Car to the Skip Bridge structure.
- Once the skip is secure, all personnel must vacate the Skip Bridge area.
- Tata Electrical Engineering Department to operate Skip Hoist until sufficient slack rope is obtained on the winch drum.
- Sign off PBS/ATW

Disconnection/Removal of the Skip Hoist Ropes

- Obtain COI/EOP on Skip Hoist drives. **TATA TO ISOLATE**
- Obtain Fluid Power Isolation certificate on Skip Pit Hydraulics. **TATA TO ISOLATE**.
- Sign on at Blast Furnace Permit Office.
- Sign on PBS/ATW
- Position rope stands at underside of Skip Bridge.
- Use a Tele-Handler to lift new rope reels onto rope stands – the reel should be orientated so that the rope uncoils from the top of the reel and aligned as close as possible to the direction of rope travel up the skip bridge.
- Remove storage packaging from around the new ropes and release the tail end from the reels.
- Attach the appropriate rope grip (or sock) to the tail end of the ropes. (see Addendum to procedure for specification of rope grip and details relating to the correct fitting of same)
- Remove the guarding from around the Skip Hoist Drum and store in a safe location.
- Remove/loosen the Slack-Rope Limit assemblies.
- Pull slack rope away from the centre of the rope barrel and record the measurement.
- Cut the end section of the old ropes off the Hoist Drum (by burning) and remove from site for disposal.
- Feed the old ropes out through the aperture in the west wall of the Hoist House.
- Attach sheave blocks to brackets on the concrete plinth outside the Hoist House (opposite the aperture in the wall).
- Feed old ropes through the sheave blocks and attach onto the towing arm of the Tele-Handler.

Skip Bridge Incline

- Arrange erection of scaffold on skip bridge incline (alongside skip) to provide access to skip car linkage and rope ends.

- Anchor old ropes using 1 tonne chain blocks and attach to the Skip Bridge structure.
- Cut old ropes (by burning) at end of splices and prepare end of cut rope to receive rope stocking. The strands on the rope should be fused together by the burning operation.
- Remove old spliced ends from Skip Car linkage arms and remove from site for disposal.
- Uncoil the new ropes (with grips attached) from their reels and lift the ends up through the window at the bottom of the Skip Bridge.
- Position the new rope ends alongside the old ropes.
- Attach the rope grips onto the ends of the old ropes. [Refer again to Addendum for instructions relating to installation of rope grips]
- Remove the chain block anchors from the old ropes.
- Tata must check the connection of the new ropes to old (i.e. the grip installation) at this stage.

Installation of New Ropes

- Tata must inspect and confirm acceptance of the old to new rope connections prior pulling commencing.
- Tata to ensure that **NO PERSONNEL** are in the following vicinities while the pulling of the ropes.
- **All safety watchmen to be in radio contact with the PICWP situated on the Skip Bridge Road. Tata to confirm with the working party when the pulling of new ropes can begin.**
- With the new ropes attached to the old ropes (at the base of the skip bridge), and the other end of the old ropes attached to the towing arm on the Tele-Handler, the installation of the new ropes can commence - this is achieved by pulling the old ropes off the sheave system, and hence the new ropes on. Both ropes can be pulled simultaneously.
- Using radio communication, the PICWP must check that all safety watchmen are in position and that all areas identified above have been vacated. Once confirmed, the telehandler driver can be instructed to drive at slow speed in a southerly direction along the skip road.
- During the pulling operation, the condition of the rope grip connection must be monitored as it travels up the skip bridge incline. This can be achieved by a nominated person walking with the grip up the skip bridge stairway.
- The length/distance of each rope pull must be maximised so as to minimise the number of stop/start occurrences. To achieve this, every effort must be made to pull the ropes through the slag pool road area. (see Pre-Stop Preparation). For any re-positioning of the pulling equipment, the ropes must be disconnected and re-connected to the telehandler in the same manner. If there is a planned pause in the pulling operation, the grip should be positioned away from any snagging points.
- Installation is complete once all new rope has been pulled around each sheave, the grip has been pulled through the aperture in the hoist house, and the thimble ends of both new ropes are free of the reels and located adjacent to the skip.
- Fit thimbles (or anchor ends) onto the Skip Car linkages, and secure with the pins provided.
- Carry out a final pull of the ropes with the telehandler in very slow speed - this will take up any slack in the ropes on the skip bridge.
- Release the ropes from the towing arm on the Tele-Handler and ensure the ropes are positioned in a safe location.
- Remove rope stands and reels to a safe location off the road.
- Arrange for scaffold adjacent to skip to be stripped at this stage.

Connection of New Ropes to Hoist Drum

- Proceed to hand feed the new ropes around the Hoist Drum and measure the rope length to determine a cut point (refer to section 2, step L).
- Obtain a Confined Space permit (from nominated Tata representative) to allow access inside skip hoist drum. A safety man must be employed immediately outside the drum to monitor conditions for the duration of work inside the drum.

- *Disconnect the old rope ends from inside the drum by loosening the bolts on the anchor blocks and feeding the ropes ends out through the side of the drum.*
- *Feed the ends of the new ropes through the openings in the drum wall.*
- *Connect the new rope ends to the drum by securing the bolts on the associated anchor blocks.*
- *Refit the slack rope limit assemblies and set-up as follows. Position the limit arm mechanism into position and partially secure bolts (M12 x 50mm long hex bolts).*
- *The limit bar should then be levelled out using counter weights until it is horizontal. The limit bar should then be positioned parallel to the rope along the drum at one rope diameter (i.e. 38mm, Drawing Ref: 2553.20.17.11.107)*
- *Cancel COI/EOP on Skip Hoist drives.*
- *Sign off PBS/ATW*

Taking Up Slack Rope and Releasing Skip Car

- *Supply JMS*
- *Sign on PBS/ATW*
- *Working under the control and direction of Tata Electrical Engineering Department (Authorised Person)*
- *Tata Electrical Engineering department to operate the skip hoist to take up the slack rope and raise the skip approximately one foot up the incline.*
- *Tata Electrical Engineering Department to isolate Skip Hoist drive.*
- *Remove the wire slings and shackles used to anchor the skip to the skip bridge structure. Again, full body harnesses must be worn if access is required onto the incline.*
- *All personnel must now vacate the skip bridge area.*
- *Tata Electrical Engineering department to operate the skip hoist to take up any remaining slack rope.*
- *Tata Electrical Engineering Department to again isolate the Skip Hoist drive.*
- *Once the limit is finally set, secure the mechanism and replace all guards around the drum.*
- *Sign off PBS/ATW*

Inclusions

- JMS
- Site Transport
- Telehadler
- PPE
- Personal 3-in-1 Gas Monitors
- Welding Set
- Burning Equipment
- Impact guns and sockets
- Consumables
- Pull Lifts
- Radios
- Bunting Tape

Exclusions

Spares

W5402285 48MM DIA.SKIP HOIST ROPES FOR NOS.4 & 5

80019578 TOOL:BANDING,5/8"

80020535 CLAMP: K-SERIES UNVRSL PREFORM,76.2mm ID

W6300162 STOCKING-CABLE:ROPE OPEN END,38-50mm,1.2

D – Email Communications with Bridon Ropes

Section 6.2. discussed the requirement for the discard criteria in ISO 4309 to be followed as an indication for a wire rope change. The Email in appendix pages XVII – XVIII shows the email conversation between John McDyer and Bridon Bekaert regarding this topic.

Good Morning John

Thank you for your question via our website.

The change out period for ropes is usually either based upon historic usage and a known period of time or through visual examination and the discard criteria given in ISO 4309.

We do carry out physical fatigue tests on these ropes, but this is really only a comparison against other constructions as the tests are carried out on the same machine with the same sheaves and loading factors. Unfortunately, our machines do not replicate an actual system that the ropes are used on.

We also carry out fatigue calculations for ropes based upon the system that they are being used on with inputs such as load, speed of operation, sheave diameters, number and type of bends but these don't take into consideration other factors such as weather, variable loads, maintenance etc.

We would therefore suggest that visual inspection should be used as the main discard criteria for a rope with time being used as guidance for a planned change before discard criteria is reached.

There is the option to look at continuous monitoring systems which the ropes can either run through all the time or where they can be used during maintenance periods. These systems can either be magnetic testing machines which look for wire breaks, corrosion and loss of steel area or a combination of magnetic and visual examination which also looks for changes in lay length, diameter changes, lubricant condition and rope deformations. When used continuously these systems can often be viewed remotely reducing the amount of downtime required to inspect the rope.

If you would like more details on these monitoring systems please let me know and we can discuss further with our UK distributor Certex or our own Services team

Regards Owen

We utilise a 48mm 6x41 Bristar PI wire rope and I am questioning if the manufacturer (yourselves) put a fatigue life on the wire rope or should it be completely assessed using the ISO4309 discard criteria? I.e., should they be changed out at a certain number of cycles or duration.

We currently use these ropes on a skip car hoist and change them out at 2.5mt of material moved (Approx 18-19 months). We rarely if ever encounter any discard level degradation when changing the wire ropes.



Owen Ketteringham

Technical Applications Lead



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E – MRT Reports

Section 5 of the document discussed key points of the results of the MRT. A full copy of the results can be seen in appendix pages XXII – XXXVI.

E.1. Rope 1

MRT REPORT IN ACCORDANCE WITH ISO-4309

TATA STEEL

MRT REPORT / JOB NUMBER- 7001384-1



Date of Inspection: 19/01/23
Order Number: 7001384-1
Rope ID Number: N/A
Engineer: Mateusz Jopa



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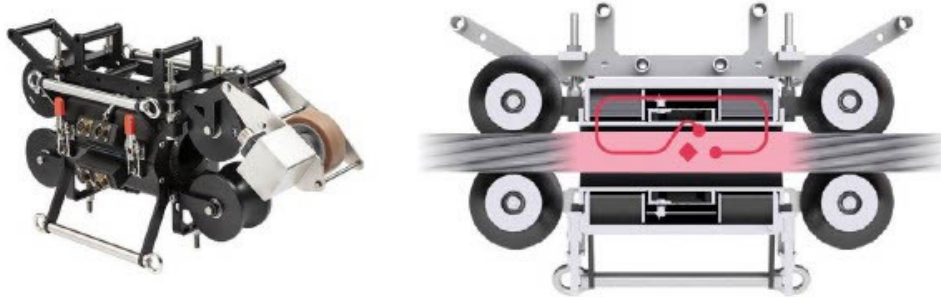
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MRT DEVICE SPECIFICATIONS

AMC ROPE



Manufacturer: AMC
Model: Rope 65
Weight: 32KG
Dimensions: 75 x 55 x 45cm
Inspection Diameter Range: 20 - 65 mm
Field Source: Permanent Magnet (NdFeB)
Sensor Type: Coils; Hall Effect Sensor
Signal Type: LF
Signal Accuracy: In accordance with EN12927
Maximum Test Speed: 8 m/s

TEST CONDITIONS

Winch Speed / Speed of Wire: Speed 2
Direction of Wire Travel: Directly off Reel,
plain end first, sock end tail.
Location of Device: 5mtr from spooler

Test was carried out with the MRT device secured onto a stable structure then clamped onto the wire and spooled onto a Reel.

Total of 160 meters of rope was inspected.



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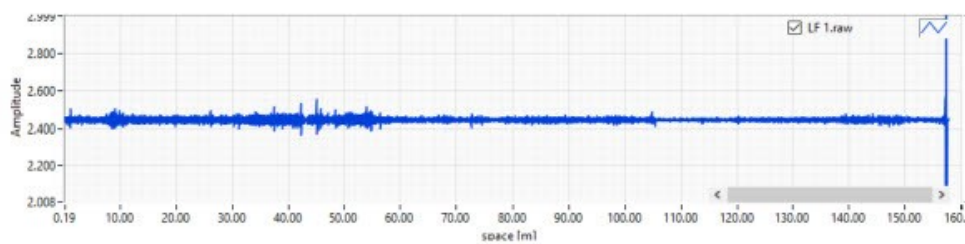
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MRT RESULTS

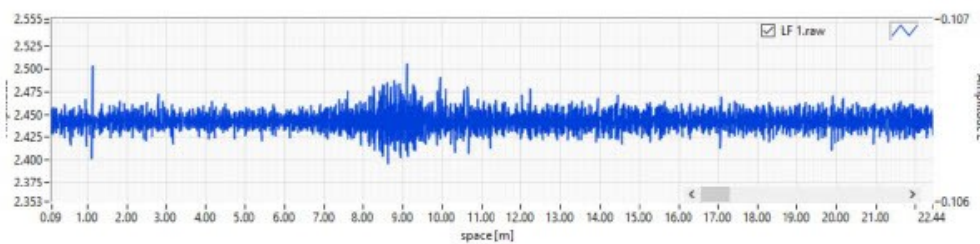
FULL TEST DATA ROPE 1

Below is a full measurement of the tested wire approximately 160mtrs.
At 1m is the test wire indicating 1 broken wire



0m to 22.5m of data

Distance	Description of Findings	
1m	Single Broken Wire	Test wire
8.5m - 9.5m	Internal Corrosion	Potential
9m	Single Broken Wire	internal



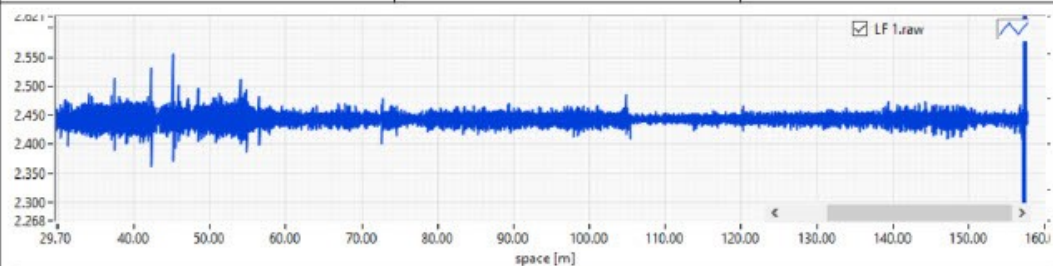
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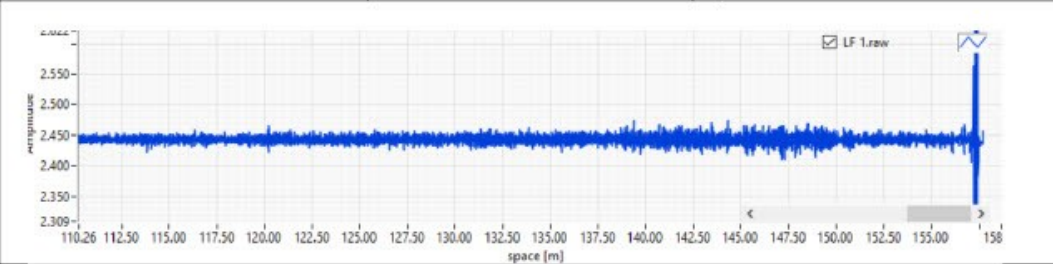
30m to 160m of data

Distance	Description of Findings	
30m-55m 77m-105m	Internal Corrosion	Potential
31m,38m,42m,46m,55m,56m,73m,105m	Single Broken Wires	Internal
42m-43m	Multiple Broken Wires	Internal
44m	Diameter	Speed



110m to 160m of Data

Distance	Description of Findings	
120m	Single Broken Wires	Potentially internal
138m-150m	Internal Corrosion	Potentially Internal
157m	End of Wire	Speed



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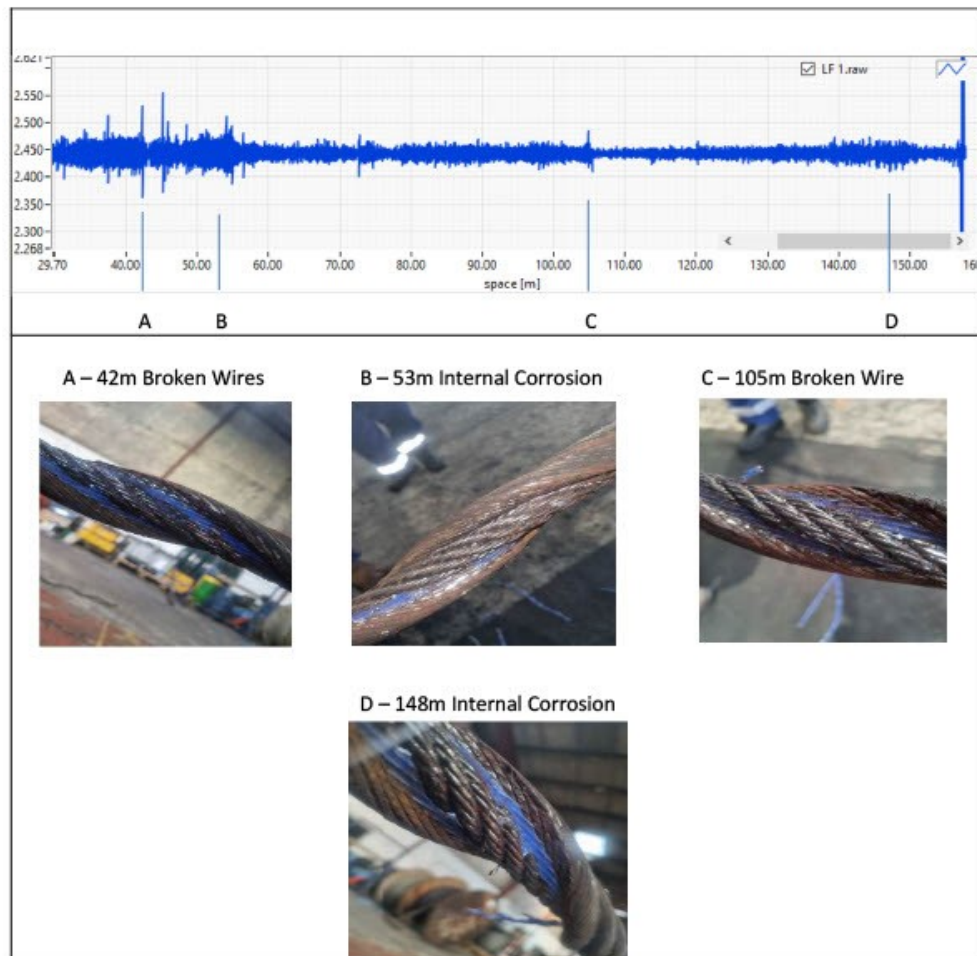
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TEST SUMMARY

At time of inspection multiple potential defect indications were found at various lengths throughout 160-meter length inspected. These possible indications are shown above in the MRT graphs highlighted by the fluctuations in the MRT graph readings noted above.

Pictures below show the wire opened up to further examine the defects highlighted by the MRT graph.



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CONCLUSION

- MRT graph results shows indication of multiple possible defects in the rope
- Further examination was carried out to support the MRT findings, pictures in test summary further support this data.
- Take out of service.

An external thorough examination of the rope was also conducted.



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E.2. Rope 2

MRT REPORT IN ACCORDANCE WITH ISO-4309

TATA STEEL

MRT REPORT / JOB NUMBER- 7001384-1



Date of Inspection: 19/01/23
Order Number: 7001384-1
Rope ID Number: N/A
Engineer: Mateusz Jopa



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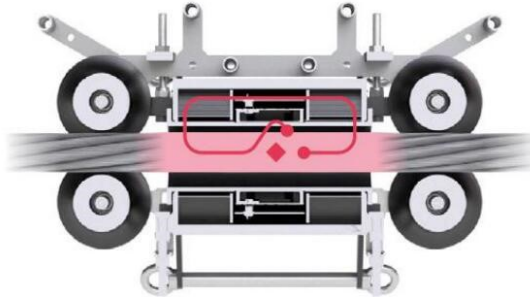
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MRT DEVICE SPECIFICATIONS

AMC ROPE



Manufacturer: AMC
Model: Rope 65
Weight: 32KG
Dimensions: 75 x 55 x 45cm
Inspection Diameter Range: 20 - 65 mm
Field Source: Permanent Magnet (NdFeB)
Sensor Type: Coils; Hall Effect Sensor
Signal Type: LF
Signal Accuracy: In accordance with EN12927
Maximum Test Speed: 8 m/s

TEST CONDITIONS

Winch Speed / Speed of Wire: Speed 2
Direction of Wire Travel: Directly off Reel,
plain end first, sock end tail.
Location of Device: 5mtr from spooler

Test was carried out with the MRT device secured onto a stable structure then clamped onto the wire and spooled onto a Reel.

Total of 160 meters of rope was inspected.

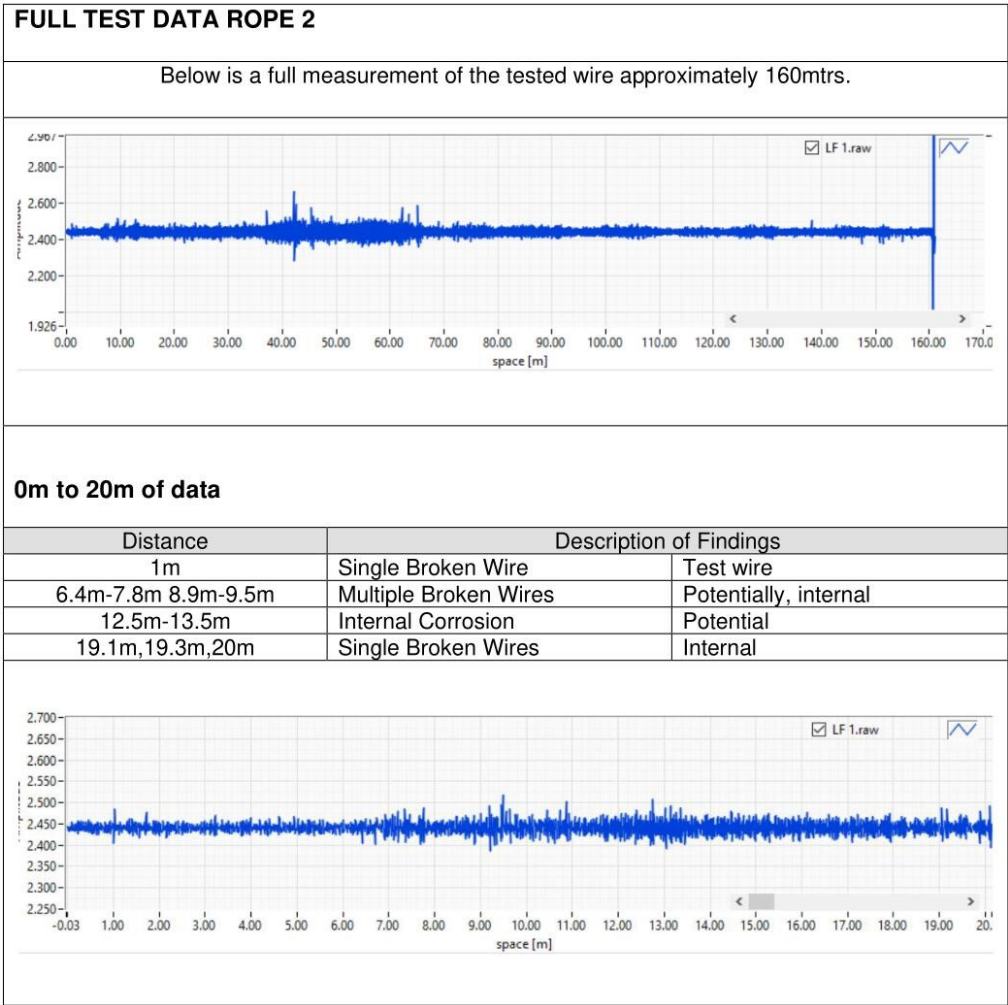


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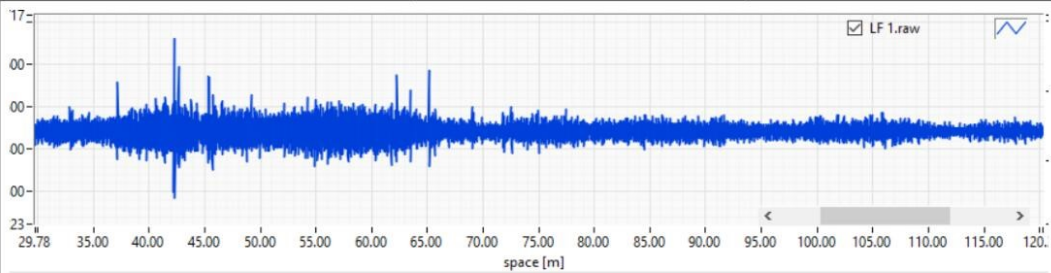


MRT RESULTS



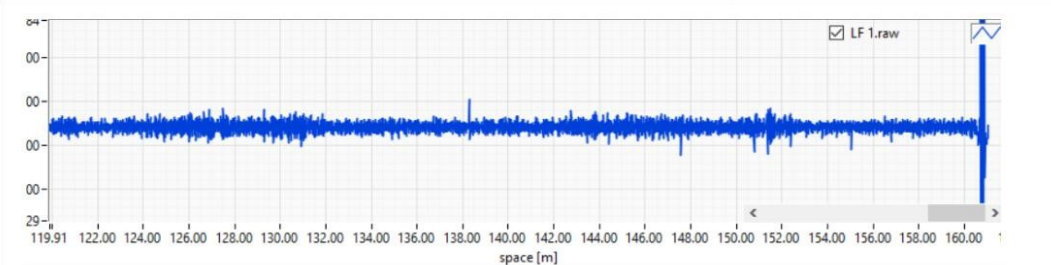
30m to 120m of data

Distance	Description of Findings	
38m-67m	Internal Corrosion	Potential
38m,46m,63m,64m,65m	Single Broken Wires	Internal
42m-43m	Multiple Broken Wires	Internal
73m-110m	Movement in Wire	Speed



120m to 160m of Data

Distance	Description of Findings	
138.1m,147m,150.9m,151.5m,152.5m,155m	Single Broken Wires	Potentially internal
160m	End of Rope	Speed



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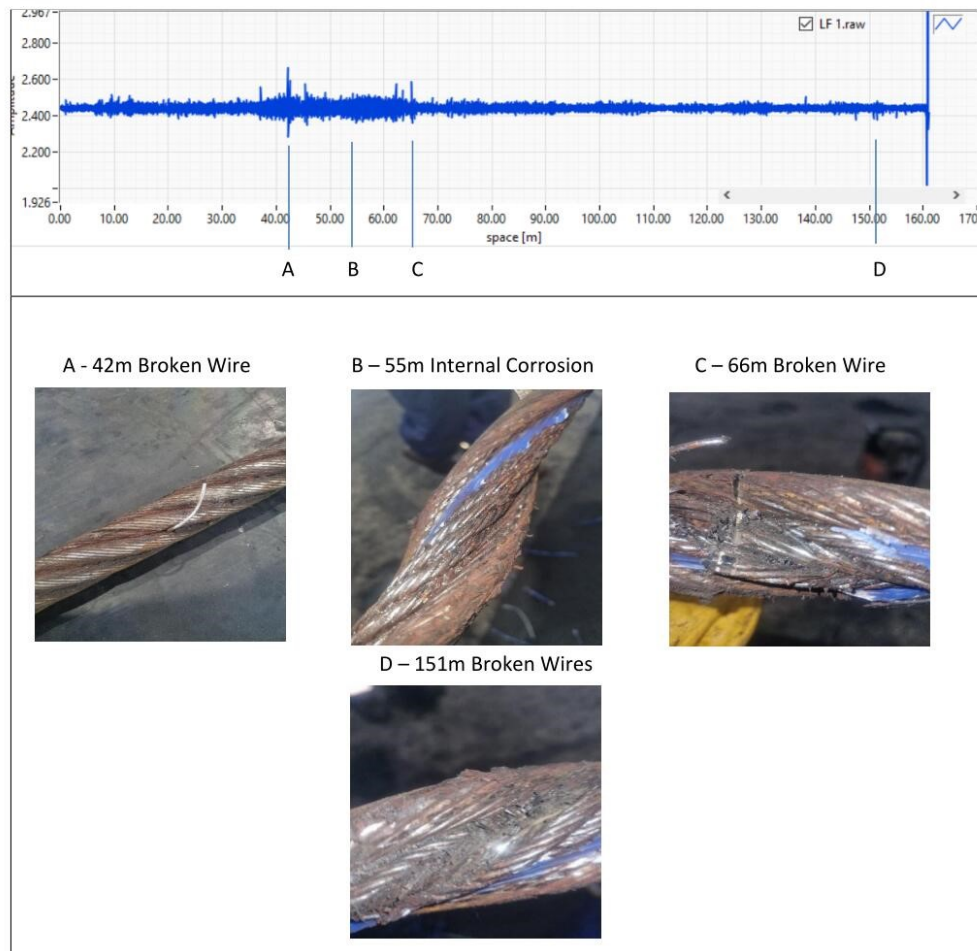
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TEST SUMMARY

At time of inspection multiple potential defect indications were found at various lengths throughout 160-meter length inspected. These possible indications are shown above in the MRT graphs highlighted by the fluctuations in the MRT graph readings noted above.

Pictures below show the wire opened up to further examine the defects highlighted by the MRT graph.



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CONCLUSION

- MRT graph results show indications of multiple possible defects in the rope.
- Further examination was carried out to support the MRT findings, pictures in test summary further support this data.
- Take out of service.

An external thorough examination of the rope was also conducted.



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