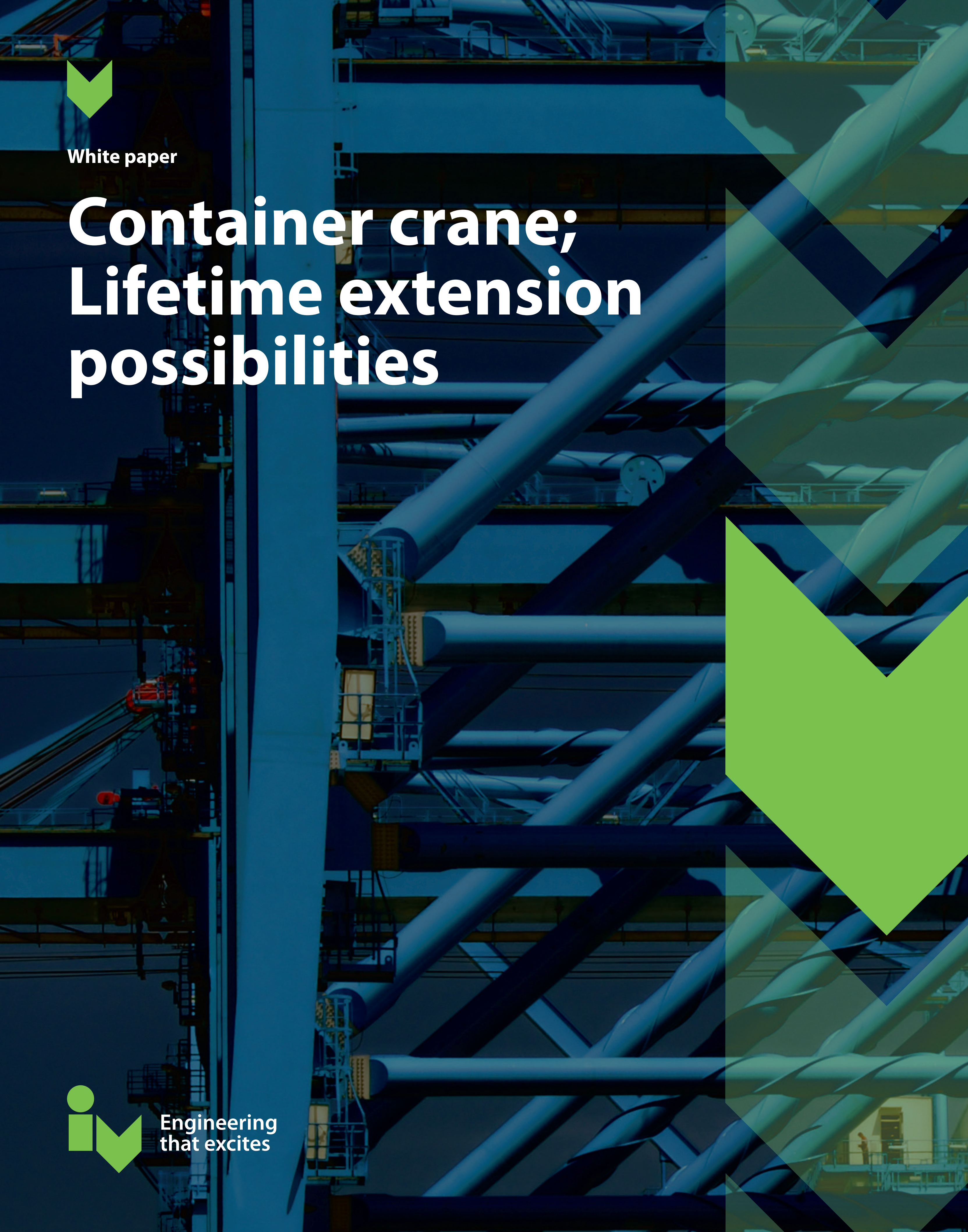


White paper

Container crane; Lifetime extension possibilities

Engineering
that excites

How to safely extend the service life of existing cranes

Many container cranes are reaching the end of their design lifetime. Replacing a crane is a considerable investment and not always necessary. Iv has extensive experience in lifetime studies for container cranes. This white paper explains when lifetime extension could be a suitable option and how this can be achieved. In some cases, cranes have operated an additional ten years with only minor adjustments.

Cranes are typically designed to be in service for approximately 2,000,000 cycles. However, many cranes are used long beyond their design life. Safe operation beyond the original design can be realised with Iv's workflow for crane life time extensions.

1. Fatigue: introduction

In consultation with the owner, the crane's usage is estimated during the design phase. The design usage consists of the expected number of cycles per year, the average and maximum container weights to be handled, the pick-up and set-down positions of the container, and the desired lifetime of the crane. Based on these elements, the engineer designs the crane. However, the actual usage of the crane may differ.

The actual lifetime of the crane's steel structure is based on the fatigue damage accumulated during usage. Due to the frequent loading of the crane, micro-cracks form and can propagate and grow into critical cracks in the structural steel. Fatigue failure of the steel structure occurs when the cracks have propagated to such an extent that the crane can no longer function safely.

Fatigue failure of the structural steel can be estimated using the so-called Wöhler curve.

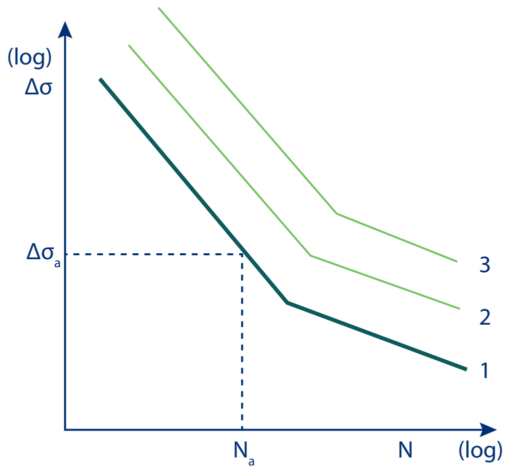


Figure 1: Example of Wöhler curve

A Wöhler curve (also known as an S-N curve) plots the allowable number of cycles to failure (Na) for a specific stress variation level (Δσa). The quality of the constructional detail determines the location of the slope of the S-N curve (1, 2, 3 etc.) and, therefore, the characteristic stress range corresponding to a number of stress cycles. For this number of stress cycles, the survival probability of the steel is 97.7%.

In various standards, constructional details are grouped into notch classifications with the same Wöhler curve characteristics. These include welded and non-welded connections. For welded connections, the notch class may depend not only on the geometry of the connection but also on the weld quality. An example of a constructional detail whereby the notch class depends on the geometry and weld quality is shown in Figure 2.

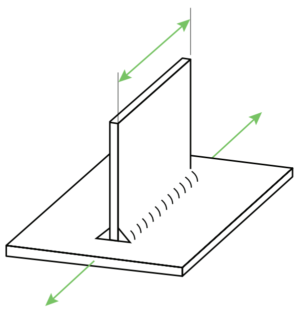
Detail No.	$\Delta\sigma_c$ $\Delta\tau_c$ N/mm²	Constructional detail
3.24	m = 3	 Continuous component with parts ending perpendicularly
	80	$l \leq 50$ mm
	71	50 mm < $l \leq 100$ mm
	63	100 mm < $l \leq 300$ mm
	56	$l \leq 300$ mm

Figure 2: Characteristic fatigue strength Δσc of constructional detail [NEN-EN 13001-3-1:2012+A2:2018]

In reality, not all containers are lifted from the maximum outreach and set down at the maximum backreach. Therefore, the fatigue calculation needs to reflect a range of operational scenarios. A design spectrum includes different load cycles and their frequencies.

The Palmgren-Miner rule is applied to accumulate the fatigue damage. This rule states that each number of stress cycles is proportional to the total number of cycles to failure. Therefore, the damage of each load sequence can be calculated from the stress ranges within the sequence, which is then checked against the characteristic fatigue strength and the corresponding number of cycles. Subsequently, the damage per load cycle can be summed, and the total damage to the crane calculated. Since the damage is expressed as a unity check, a crane will reach its theoretical end of the lifetime when this total damage exceeds 1.

2. EN13001

The design codes used 20 years ago were less defined and therefore more conservative. For example, the FEM1.001 defines only four notch groups, which presents some room for discussion (F.E.M., 1998). However, using only four notch groups means that every detail is shifted towards the conservative side. The main differences between the old design codes and EN13001 are discussed below.

Safety factors

The difference in safety factors for structural integrity: EN13001 multiplies the load with load and safety factors (limit state method) (CEN, 2015), while FEM1.001 applies an amplifying coefficient to all loads (allowable stress method). Checks performed according to EN13001 usually result in lower unity checks.

A different calculation for fatigue life

EN13001 calculates fatigue life as cycles to failure for each individual detail, offering a more realistic approach than the general classifications used in FEM1.001. In the older method, frequently and infrequently loaded parts—such as the boom hinge and boom tip—are given the same fatigue classification. EN13001 makes a clear distinction, allowing less frequently loaded areas (e.g. the boom tip) and indirectly loaded components (e.g. the portal structure) to benefit from a more accurate assessment.

An additional advantage of EN13001 is the inclusion of more notch categories for steel structure details. This allows for a more refined fatigue assessment based on geometry and weld quality. As a result, additional fatigue life may be justified (see Figure 3).

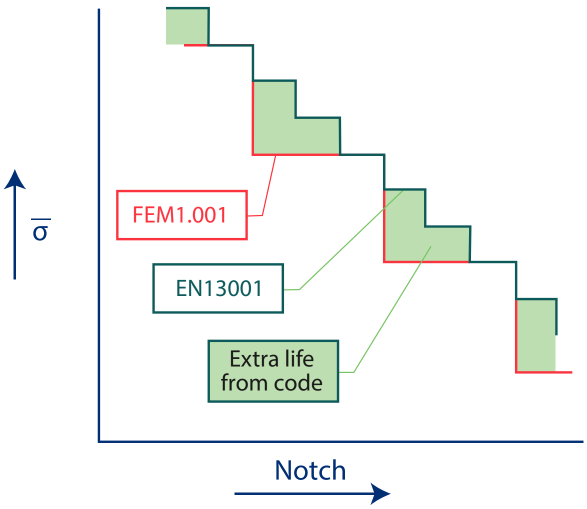


Figure 3: EN13001 has more notch categories than the FEM1.001

Benefits of lifetime extension for existing cranes

Using a classification for fatigue lifetime calculation (e.g. FEM1.001, DIN 15018) may not reflect the actual usage of the crane. By applying EN13001, the realised load spectra (which may vary due to different crane modes used in the past) and the number of previous cycles can be combined with expected future loads and spectra to assess cumulative fatigue damage. The outcome of this analysis indicates the remaining lifetime of each crane component. If certain parts fall short of the required lifetime, local improvements can be designed to extend it.

Miscellaneous

EN13001 offers further advantages compared to older standards, such as more nuanced stability check and wheel load calculations. These can provide valuable input for the civil engineering calculations at terminals. However, this topic falls outside the scope of this white paper. For more information, please contact Iv.

3. Modern software

The ongoing development of software and hardware creates new possibilities in engineering. In the past, STS cranes were often analysed using only simple beam models since these can be quickly prepared and modified, often included code checks, and required low levels of computing power.

Nowadays, computing power is not an issue and geometries are easily generated or linked to CAD software. Iv creates parametric models with the level of detail required for fatigue analysis. This provides an excellent indication of stress concentrations, correct stiffness, the behaviour of joints, and secondary effects such as in-plane bending stresses.Generic FEA tools are not always fully suitable for fatigue assessments, as code checks are often not integrated. To address this, a fatigue analysis tool has been developed for use with Ansys Mechanical. This enables efficient and automated fatigue evaluations of welds and other details. The analysis can be based on cyclic or spectral loading (the latter typically not relevant for onshore cranes). Fatigue damage or the required notch category is visualised within the 3D model (see Figure 4).

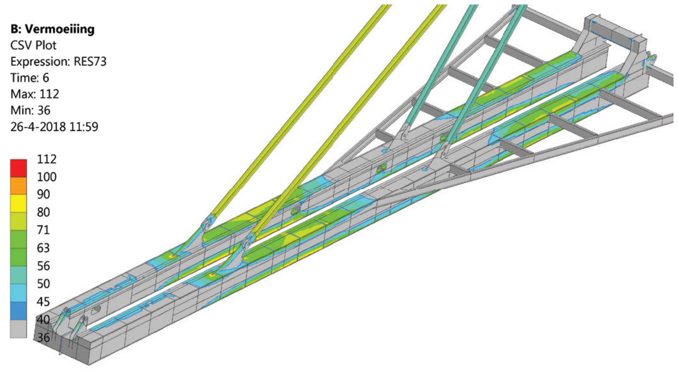


Figure 4: Lowest required notch-group

This approach enables detailed evaluation of every weld in a new design and helps optimise weld connections.

In the case of lifetime extension, critical areas can be identified quickly and with precision. Automated fatigue calculation reduces the risk of manual errors and shortens lead times.

Specialised software has been developed to perform fatigue assessments according to EN13001, EN1993-1-9, and DNVGL-RP-C203. This enables accurate and efficient evaluation of crane structures, both for new designs and for lifetime extension studies. The software is used in combination with engineering expertise in crane structures and fatigue behaviour.

4. CO_2 footprint

Extending the life time of a crane contributes positively to long-term environmental impact. For example, a modern STS crane weighs approximately 1,400 tonnes (MDPI, 2021). Considering that one tonne of construction steel generates roughly 1.9 tonnes of CO_2, the production of a single crane results in approximately 2,660 tonnes of CO_2 emissions. Transport, coating, and demolition also contribute to the overall footprint, although these are not included in this calculation. Extending the operational life from 25 to 35 years reduces average CO_2 emissions from 106.4 tonnes per year to 76 tonnes per year, a reduction of approximately 29%. Several governments offer, subsidies to support projects that contribute to sustainability goals. Iv is happy to assist in applying for these subsidies.

5. Problem solving

Although the design codes used in the past were generally more conservative and less defined than the current EN13001 standard, this does not guarantee that additional lifetime can be achieved. In some cases, structural components may be shown to reach the end of their fatigue life sooner than originally estimated.

This is often due to improved understanding of fatigue-sensitive details over time. As a result, new assessments may yield less favourable outcomes.

Mitigating the risk

When problem areas pose a threat to continued crane operation, four potential strategies can be considered:

1. Avoid – Cease all crane operations to eliminate the risk entirely.
2. Mitigate – Modify the problematic areas or adjust usage to reduce or eliminate the threat.
3. Transfer – Engage third-party expertise to manage or monitor the risk.
4. Accept – Take no action and accept the consequences associated risk.

In practice, the first, second and fourth options are rarely viable:

- Avoiding is extremely costly, as it effectively writes off the crane, often creating major operational challenges. A replacement STS crane may cost several million euros and can take years to commission.
- Mitigating through structural modifications may be possible in some cases, but not always effective. Such modifications can degrade fatigue details, and on-site repairs are often of lower quality than factory production, potentially worsening the situation.
- Accepting the risk is not realistic due to the presence of personnel and safety regulations.

This leaves the third strategy: Transfer. Even in cases where no theoretical fatigue life remains, regular monitoring of critical areas can offer a practical and safe path to continued use.

Monitoring critical areas

Many structural issues can be managed by monitoring known fatigue-sensitive areas. This can be achieved using conventional non-destructive testing (NDT) methods such as TOFD (Time of Flight Diffraction), PAUT (Phased Array Ultrasonic Testing), and ET (Eddy Current Testing). However, these inspections must be performed at regular intervals, a balance between safety, cost, and crane availability that is difficult to quantify.

A more robust approach is continuous monitoring, which allows for uninterrupted crane operation without compromising safety.

Continuous monitoring with ferromagnetic sensors
Ferromagnetic sensors based on the Villari effect provide a promising alternative. The Villari effect describes how mechanical stress in ferrous metals affects the local magnetic field. When stress is applied, the magnetic field changes; once the stress is removed, the field returns to its original state.

These magnetic field variations can be used to detect crack growth in welds. As a crack propagates, stress increases at the crack tips and decreases along the sides. A finite element model (FEM) illustrates this effect for various crack sizes. The corresponding changes in magnetic field are measured by the sensors and reported continuously.

Sensor installation and operation
The sensor strips are applied directly to the welds using a high-quality adhesive, eliminating the need to remove coating or paint. Once installed, the system operates autonomously for approximately two years. In the event of crack growth, the asset owner is immediately alerted, and expert advice can be provided promptly to guide further action.

6. Plan of approach

Every crane lifetime extension study is unique. Not only do the crane designs vary, but also the usage of the cranes can differ (e.g. load spectrum; stacking function; etc.).
Our lifetime extension studies are performed in the following steps:

1. **Collecting input:** Usually, the crane owner has all the original drawings and calculations of the crane. Information regarding any major adjustments to the crane is also required for the lifetime study. Additionally, insight into the usage of the crane, the number of load cycles, and the mass of the lifted containers provides valuable input for the analysis. These figures were usually conservatively estimated during the design process. When actual data is used, the calculation becomes more realistic.
   In cases where documentation is incomplete, reverse engineering and 3D measurements can be applied to reconstruct the missing information.
2. **Modelling:** Based on the drawings (and, when necessary, on the reverse engineering), we build our FEA models to simulate the crane structure accurately.
3. **Load spectrum:** A realistic load spectrum is essential. If crane usage has changed over time, lifetime calculations are performed in phases to reflect damage accumulation.
4. **Analysis:** Using the model and the load spectrum, we can perform our analysis to identify critical areas. Any points of attention will be analysed in more detail to gain insight into the accumulation of damage and the remaining lifetime.
5. **Crane inspection:** Based on the analysis, a deeper understanding is obtained of which parts require closer inspection. We prefer to conduct crane inspections together with the crane operator and maintenance personnel. These people are fully aware of any underperforming part(s) of the crane or previously experienced issues. This provides beneficial information in the following steps.
6. **Solutions, calculations & drawings:** Depending on the results, local reinforcement, periodic inspection or continuous monitoring may be advised.
7. **Reporting:** All findings are documented in a comprehensive report.
8. **Sensor placement and monitoring:** When continuous monitoring is advised, a detailed sensor placement plan is developed. The positioning of the sensors is critical to ensure the reliability and accuracy of the measurements. Based on the preceding steps, Iv has all the necessary information to prepare this plan and to coordinate and/or supervise the sensor installation process. Once the sensors are installed, sensor data is continuously monitored. If crack growth is detected, the asset owner will be promptly notified and advised on the appropriate course of action. This may involve urgent repairs in the case of a critical connection, or planning maintenance in the coming months to prevent unplanned downtime.

9. **Project management:** In coordination with the client, Iv can also assist with the RFQ documentation and management. Iv has a wealth of experience in managing crane modification projects. We are frequently involved in, for example, selecting (local) contractors to bid on the required modifications, managing the tender process, providing advice with regard to the awarding, and managing the construction and commissioning process.

Electrical and mechanical equipment can be added to the scope of Iv. Fatigue calculations can be helpful, and during the inspections, extra attention can be given to specific mechanical and electrical parts.

Frequently, the electrical systems should be overhauled since they may be outdated by the end of the crane's design life. Mechanical equipment may last longer than the crane's design life (for example, the winch shaft is usually designed for an infinite lifetime). Mechanical parts are checked during the crane inspection. Wearing parts fall under the OPEX budget and are therefore not included.

7. Financial considerations

A lifetime study provides greater insight into the remaining lifetime, the safety of the cranes and the necessary budget reservations.
When all the details regarding the required repairs, modifications and a monitoring plan using ferro magnetic sensors are defined, an estimate of the involved costs can be generated. Usually, the investment and amortization of a lifetime extension project are far more lucrative than buying new cranes.

Upgrading

If an upgrade is being considered (e.g. boom extension or heightening), it is advisable to first evaluate whether the current structure can support such changes. Combining an upgrade with lifetime extension may provide additional benefits.

8. Conclusion

Applying EN 13001 in combination with Iv's fatigue assessment software, our experienced engineers are typically able to extend the service life of cranes with minimal cost impact. In cases where critical areas with limited remaining fatigue life are identified, a tailored monitoring plan can be quickly developed to ensure safe operation.

As such, a lifetime assessment conducted by Iv represents a valuable investment—whether it leads to life extension or provides the insights needed to manage structural risks effectively.

About Iv

We are Iv. We are Engineers. Engineers dedicated to solving the most complex issues. The greatest challenges of our time. Our specialists devise solutions for the energy transition, the effects of climate change and to ensure a safe and resilient society. We design offshore wind platforms, submarines, and the world's largest lock complexes. Essentially, we design anything that requires a high level of technical expertise and multidisciplinary knowledge. The diversity of our work is unmatched by any other engineering company, and we deliver results that genuinely benefit society. This is what we call: Engineering that excites.

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Would you like to know more about the possibilities for your project?

At Iv, we would be happy to share our ideas and knowledge and provide a quotation.

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