BROMMA

Evolution of scientific methods

for structural life assessment and its application on lightweight spreader design

White Paper

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Contents

About Bromma
Bromma is the industry market leader in ship-to-shore spreaders, mobile harbour crane spreaders, and yard crane spreaders. A pioneer in the container handling industry, Bromma is focused on lifting the productivity of its customers through more reliable spreaders. Bromma has delivered crane spreaders to 500 terminals in 90 nations on 6 continents, and Bromma spreaders are in service today at 99 out of the world's largest 100 container ports. Bromma's industry-leading all-electrics spreaders and recent products such as the Spreader Monitoring System are part of this continuing effort.

Executive brief

There are no reasons to suspect that manufacturers of steel structures are not conforming to the standards specified, but the key question is whether the standards are up-to-date with reality.
This white paper addresses how the life length assessment of complex steel structures used in crane spreaders are applied and how the application relates to reality.

The studies performed have already influenced the design of steel structures and are expected to play an even more important role in the future, as the industry realises the discrepancy between reality and the standards applied.

Bromma is engaged in industry supported, academic research projects, one of which have focused on lightweight welded steel structures including the design, manufacturing and life length assessment methods used.

This white paper reveals that different kinds of fatigue strength assessment methods show very different results. More advanced methods reveal sensitive stress zones in the steel structures more precisely. The results from assessments using "simplier" methods therefore indicate a longer life length compared to the more advanced methods. The "simpler" methods as specified in existing standards, show in addition a significant deviation to experimental tests performed depending on the location in the spreader under investigation.

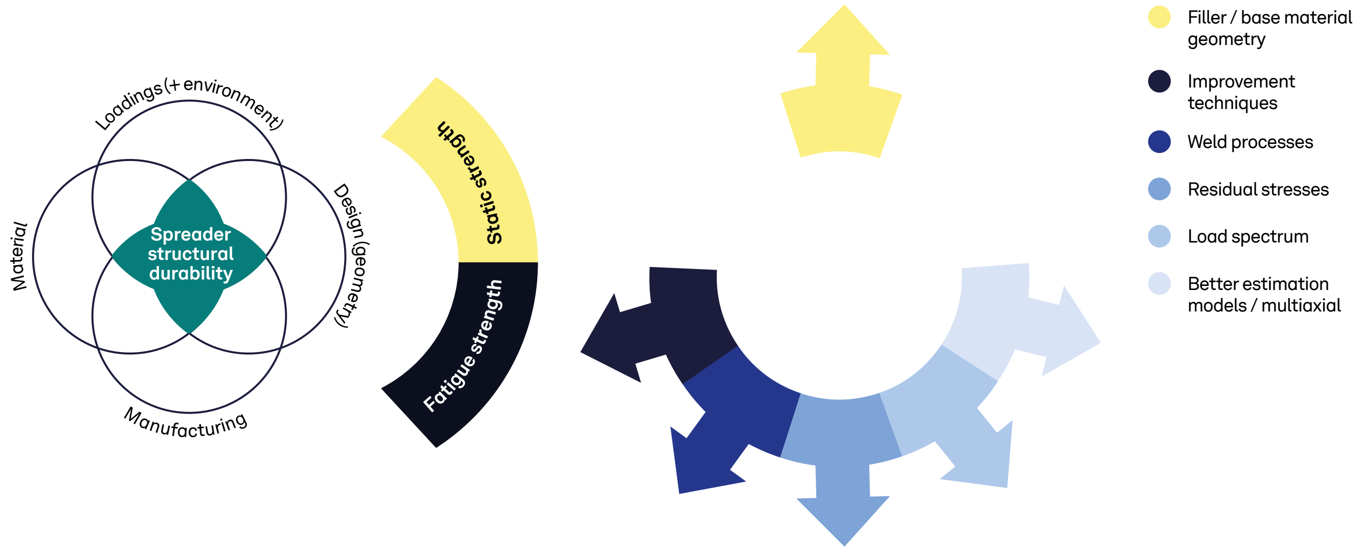
The outcome of calculation methods called for in current industry standards will likely lead to results deviating from reality. Bromma conforms to current industry standards but are in addition using significantly more advanced methods for fatigue life length assessment. The result is optimised steel structures with improved durability.

Lightweight spreaders

Structural integrity is an important aspect in spreaders where steel is the primary material and welding is a primary technique used for joining them together. Welded joints are usually critical sections prone to mechanical failures, which involve extremely complex interaction of load, time, material, manufacturing processes, and environment. Environment includes operation temperatures, and corrosive environment such as experienced in ports. Loads may be monotonic e.g. maximum safe working load limits, steady or variable e.g. lifting constant container weights all the time or lifting up variable container weights (Q class classification in EN13001[1,2,3]). The duration of these loads can vary from few seconds to minutes e.g. overloads can occur for shorter interval of time or a load due to normal container weight can occur on the structure for the whole working cycle.

One of the goals of Bromma is to develop spreaders with low weight. Lighter spreaders, reduces crane power consumption and CO_2 emissions. Bromma utilizes high strength steel in spreaders to achieve these goals. To successfully implement, such steel qualities in spreaders, it is important to understand the material characteristics as well as how to join parts of the material together and where to place the welds.

Figure 1. Structural durability



Spreader structural strength

There are thirteen common failure modes identified in metals [5]. Two of the common failure modes are:

- ductile failure
- fatigue failure

A particular welded structure such as, "a spreader", is usually designed primarily against these failures to ensure sufficient structural strength. 50 to 90 percent of all mechanical failures (not limited to spreaders) are related to fatigue.
Fatigue is a wide area, which is influenced, by various factors such as selection of fatigue strength design methodology, type of residual stresses, type of loading, welding processes, and post weld improvement methods (Figure 1).

The life span of a spreader is defined by the fatigue calculation methodologies and the materials used in the design process. It is important to define correct capacity of the welds in spreaders and know the load spectrum of the customer, i.e. Q class and average container weight handled. Design curves in the standards such as EN13001[3] available today have been developed for simple uniaxial stress states and the use of global fatigue strength assessment methodologies is recommended.

However, the welds in spreaders might be subjected to complex stress states and simple fatigue strength assessment methods may not be applicable. To design welds against these complex stress states, choice of the appropriate analysis method and definition of the loading plays a vital role. It is important to understand the interaction of stresses resulting from hoisting, slewing, trolley, gantry, and landing operations etc and their effect on the spreader structure.

Better understanding of the safe working load limits, working cycles, average container weights, and fatigue strength will make it possible to manufacture spreaders with even higher grade of high strength steels such as those with a yield strength greater than 1000MPa.

Box welded structure (a common component in spreaders) assessment

Bromma have since several years back established a profound R&D collaboration with KTH - Royal Institute of Technology Stockholm, Sweden through a joint appointment and ventures, with focus on further development of novel and advanced design methods for accurate strength and life estimation of Bromma´s products. One such project within the collaboration is project Varilight (Reduced VARIation in the manufacturing processes enabling LIGHTweight welded structures) [5]. This project was a joint effort between industrial (HIAB, Swedish Steel AB, Swedish Welding Commission, Cargotec Sweden AB Bromma Conquip and Volvo Construction Equipment) and academic partners (Chalmer Tekniska Högskolan, and KTH-Royal Institute of Technology). Among other things, a box-welded structure has been investigated within the project.

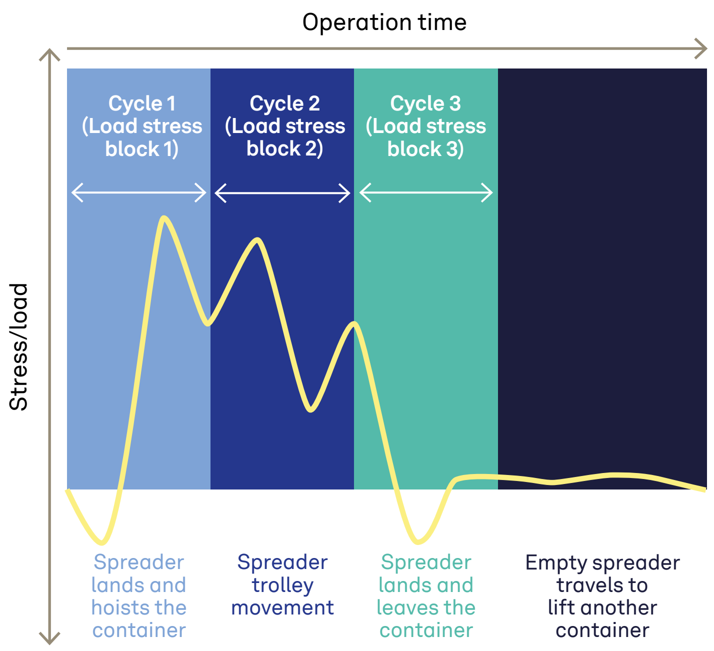
The life span of box-welded structure is influenced by the definition of working cycle, choice of fatigue strength assessment methodology, load spectrum and welding residual stresses. The most common design specification for crane spreaders today is 2 million working cycles but a specification for 4 million working cycles is starting to appear. Information about the definition of working cycle, choice of fatigue strength assessment methodology, understanding of load spectrum and behavior of spreader components subjected to fatigue loading sets the basis.

Working cycle

A typical spreader move or working cycle comprises of various movements. According to Bromma a **working cycle** is defined as a spreader landing on the load, hoisting the load, trolley movement, spreader landing and leaving the load, and empty spreader travelling back to lift another container.

This definition is in line with the working cycle definition in EN13001 and BS2573. During a typical working cycle there are stresses generated at various sections of the spreader. A typical working cycle for a spreader can result in three stress blocks as seen in Figure 2. Some of the stress blocks can be more damaging to the life of a spreader than others.

Figure 2. Working cycle definition



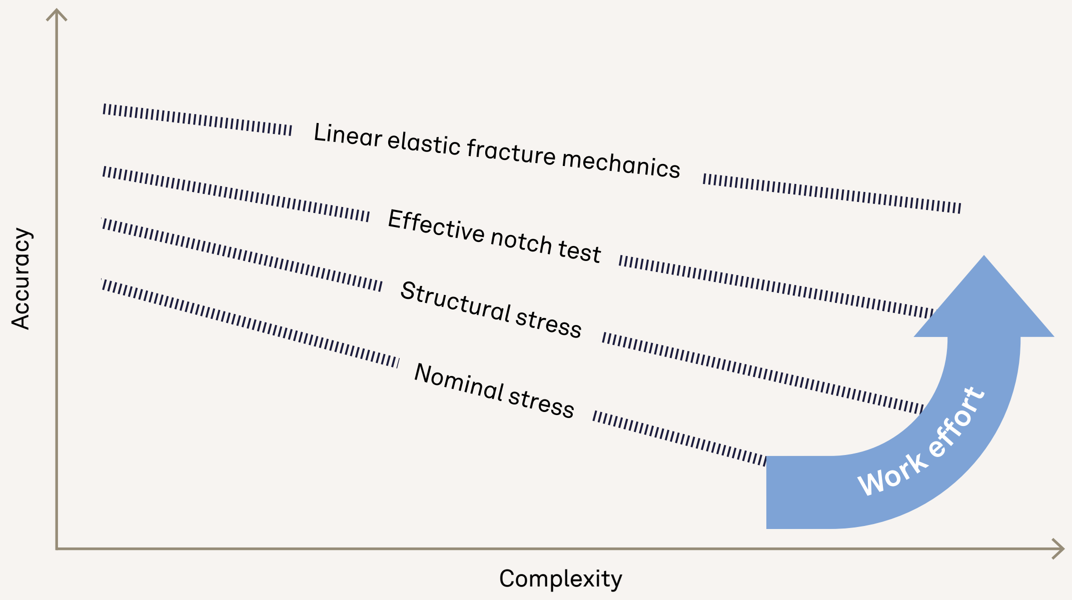
Fatigue strength assessment methodologies

Design methodologies play a vital role in the construction of lightweight structures especially deciding their life span or fatigue strength. For welded structures, stress based methods such as nominal stress, hotspot stress, and effective notch stress exists to design for high cycle fatigue such as 2 million or 4 million working cycles. Other methods e.g. strain life approaches and linear elastic fracture mechanics are also used [6,7,8]. In the design of Bromma spreaders, a combination of these methods following guidelines in EN13001 and other scientific literature [6,7] is used.

Figure 3 provides an overview about the accuracy and required effort to use these methods. It can be observed that as we move from designing simple welded joints to complex welded structures. The accuracy of most of these methods decreases. Furthermore, if we move from using global methods (nominal stress method) and start using local methods (effective notch stress method) the accuracy of estimating fatigue strength increases.

In EN13001, nominal stress method is included. The designers are free to use more advanced methods. So which methods are applicable for the assessment of complex structures like spreaders? Can all the critical areas such as box welded structure be analyzed with the methods recommended in the standards or should we use more complex fatigue strength assessment methods?

Figure 3. Fatigue strength design methodologies



Fatigue strength of box welded structure - testing and results

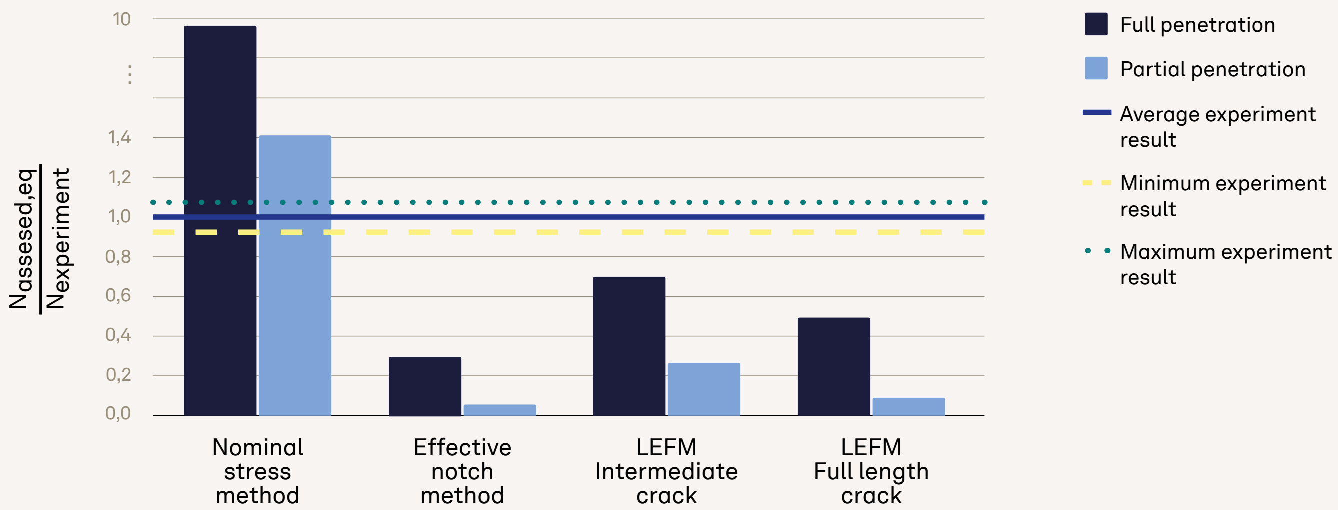
Figure 4. Fatigue testing of box welded structure

In project Varilight [5] box welded structure was analyzed using various fatigue strength assessment methodologies as described in ”Fatigue strength assessment methodologies” chapter. The same component was manufactured and tested in Bromma (Figure 4).

A round robin study for evaluating various fatigue strength assessment methodologies and studying scatter in the results was conducted in Sweden within the project [9]. In this study, the same problem was sent to various engineers (from different organizations) for calculations and they were asked to use nominal stress method for calculations and one other method of their choice. It was observed that even though the same problem was assessed by various engineers, there was a clear scatter between the life estimates by the engineers for the box structure.

In Figure 5, it can be observed that simple calculation methods, which are recommended by the standards, were over estimating the fatigue strength for this particular component whereas advanced complex fatigue strength assessment methodologies such as effective notch stress and linear elastic fracture mechanics (LEFM) are conservative to estimate the life span [10]. In the above assessment, the effect of residual stresses was also considered. Residual stresses at the weld toe and weld root were studied experimentally and by using computational weld mechanics techniques [11]. Based on the observations in Figure 5, more advanced methods are conservative and safe to use while care has to be taken when using nominal stress method.

Figure 5. Applicability of fatigue strength assesement methodologies [10]



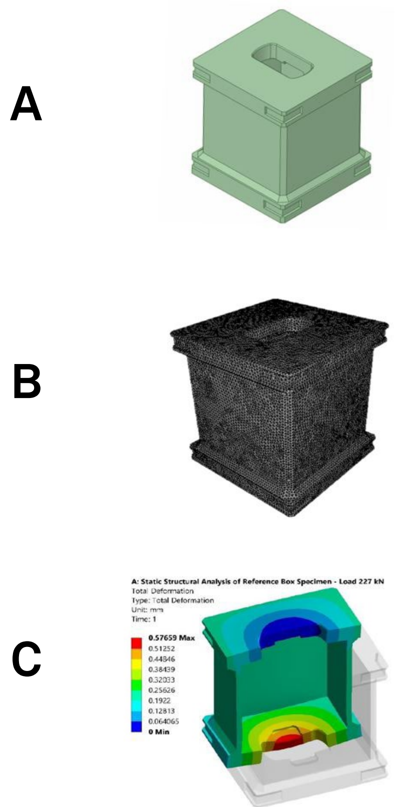


Figure 6. A) Box welded structure, (B) Meshed, (C) Deformation plot

Conclusions

Based on the analysis the following conclusion can be drawn:

- There is a significant difference in the precision of different fatigue strength evaluation methodologies, when applied on complex welded joints in crane spreaders.
- The methodologies specified in the applicable design standards are relatively “simple” methods, which in cases of complex weld details over-estimates the life length of a steel structure.
- When more advanced calculation methods are used, the outcome is more in line with reality.
- By applying the more advanced methods in the design process - even though the standards are less stringent – manufacturers of lifting equipment can lead the development towards more durable and also potentially safer steel structures and products.

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