Summary

The standardization of the container caused a revolution in cargo shipping. Dedicated ships, cranes and other equipment were developed to reduce the ship turnaround time. As part of a complete portfolio container handling equipment, Kalmar Industries develops and builds ship-to-shore cranes for loading and unloading container ships. Crane designs and calculations are based on a certain standard to guarantee safety and to enable manufacturers to comply with governmental legislation. EN13001 is a new European standard for general crane design that will replace all national standards currently in use. The main research question of this report is what the consequences of the introduction of this new standard are for the design process at Kalmar.

With the introduction of the EN13001 standard, some very common and well known concepts and methods will be replaced or modified:

- The new classification system in EN13001 lacks the classification for single components and uses average displacement and average number of accelerations to classify mechanisms.
- The limit state method is introduced as a new way of combining loads with the goal to increase accuracy: single loads are amplified by amplification factors and partial safety factors and are combined into load combinations. The resulting stresses caused by these load combinations are compared with the offset yield stress divided by a small overall safety factor.
- To take into account uncertainties in the mass of components, two Mass Distribution Classes (MDC's) are introduced. The choice of MDC has influence on the amplification factor and partial safety factor for the own weight of the crane. Ship-to-shore cranes are of MDC2 because masses exist that decrease the load effects on certain points.
- The last main new item is the way to calculate the limit design stress range for fatigue. Tests or simulations are required to obtain the stress history parameter needed for fatigue calculations. Input of the simulation is the expected use of the crane and the expected container mass distribution. Output of the simulation is a vector of the stress in time of a certain point in the crane. This vector is analyzed with the rainflow cycle counting method to determine the stress history parameter and S-Class. With these values the the limit design stress range can be calculated.

The use of the limit state method requires different amplification factors and partial safeties on the loads. The following amplification factors are important for Kalmar:

- Φ_1 for hoisting and gravity effects: because a ship-to-shore crane is a MDC2 structure this factor varies between 0,9 (for favourable mass) and 1,1 (for unfavourable mass).
- Φ_2 for hoisting unrestrained grounded loads: this factor is calculated from the Hoist Drive (HD) class, the Hoist Class (HC) and the lifting speed. The correct HC can be calculated with results from a mass-spring model of the ropes and hoist load.
- Φ_5 for loads caused by acceleration: depending on the stiffness of the crane and the drive control, this factor is between 1,25 and 1,6 and lower than the commonly used 2,0.

The introduction of Mass Distribution Classes causes a slightly higher static stresses, mainly in the lower structure of the crane, and higher reaction forces on the corners of the crane. A division of the crane in three mass groups is enough to obtain accurate results.

The new static calculation method in EN13001 (lower overall safety factors, use of amplification factors and partial safety factors) results in higher static stresses but a lower Unity Check for static stress. The main cause is the fact that no group factor is used in EN13001. The difference between the two methods (limit state method and allowable stress method) is smaller when a lower group factor is used in the old standards like NEN 2018.

The main goal of introducing a new method for fatigue calculations is to be able to take into account the 'real use' of the crane. This 'real use' is specified by the trolley position spectrum and container mass spectrum. Due to these two variables, the stress in a certain point in the crane is not constant but varies in time and causes fatigue damage. To determine the limit design stress range for a certain point in the crane, a stress-time spectrum must be generated with a simulation. This stress-time spectrum is analyzed using rainflow cycle counting software to count the number of stress cycles in the spectrum and to determine the amplitude of these cycles. With the amplitude and the number of cycles known, the stress history parameter is calculated. This stress history parameter can be used to determine the S-Class or can be used directly to calculate the limit design stress range.

The directions about buckling and plate buckling in EN13001 are limited to very specific basic cases. For more complex cases, references to literature are given. Besides the limit compressive design force a second parameter to check structural members on buckling is introduced: the allowable bow imperfection. Plate buckling calculations can be performed with a revision of the Kalmar Excel sheet based on DIN4114 or with the program FE-Beul. With the use of a finite element calculation this program can calculate complex plate buckling cases according DIN18800.

Main conclusions about the consequences of the introduction EN13001 for Kalmar are:

- New calculation methods require more input from client to specify the 'real use' of the crane.
- Most of the available Excel calculation sheets at Kalmar need a revision or remake to be able to use the limit state method according EN13001.
- With the aid of a spring-mass model the dynamic hoist factor can be calculated with a deviation of less than 1% compared to real world measurements.
- The use of MDC's results in small stress increases, mainly in the lower structure of the crane.
- Static calculations with the limit state method result in higher static stresses but a lower Unity Check.
- Performing a fatigue calculation is more complicated than in NEN/FEM and requires new methods like rainflow cycle counting. This can be performed with programs like J-Rain.
- Buckling calculations in EN13001 are only valid for simple cases; more complex cases need directions from DIN1880 or the use of a FEM program like FE-Beul.