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Evaluation of the EN 13001 Standard for Calculating Structures of Container Handling Cranes

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Contents

Introduction

Since 2012, a new European crane standard has been in use under the name EN 13001 - Cranes General Design - and consists of 3 parts. This EN 13001 standard covers a number of topics and includes the verification of the structural strength and fatigue for cranes.

This standard is directly linked to the EU Machinery Directive and is intended as an alternative to the existing national crane and industry standards such as DIN 15018 and FEM 1.001. Since EN 13001 has a legal status, crane manufacturers supplying to the EU and end users in the EU can apply this standard for all new cranes.

The approach of the standard to structural calculations of the steel frame of a crane and to fatigue, in particular, is quite different from the existing crane standards. It is worthwhile to compare these standards and to evaluate the relative impact on a crane design, e.g.: does the application of EN 13001 lead to different design choices when compared to FEM 1.001 and DIN 15018? This PEMA white paper provides a first evaluation of this question. Due to the technical character of the in-depth comparison between the standard types, this PEMA publication is mainly intended for crane designers and end users working with crane specifications and calculations.

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Background

For decades, crane design in Europe was regulated by national crane standards, such as DIN 15018 [5], NEN 2019 [6] on the one hand and FEM 1.001 [1] as the industry standard on the other hand. In 1989, the first version of the Machinery Directive was published, now known as the Machinery Directive 2006/42/EC. This directive describes essential health and safety requirements for all new machinery delivered to the European market. In the same year, the Comité Européen de Normalisation launched Technical Committee 147 with the mission to create safety standards for the design and manufacturing of heavy equipment, amongst which were cranes [9]. Within TC 147, working group WG12 was assigned with the development of the EN 13001 series of standards to ensure compliance with the Machinery Directive and to establish an interface between the user (purchaser) and the designer of the crane.

Within the scope of this paper, the following parts of EN 13001 are considered[1]:

- EN 13001-1:2015. Cranes - General design - Part 1: General principles and requirements ([2])
- EN 13001-2:2021. Crane safety – General design - Part 2: Load actions ([3])
- EN 13001-3-1+A2: 2018. Cranes – General design - Part 3-1: Limit States and proof competence of steel structures ([4])

The EN 13001 is a type C standard as stated in the EN ISO 12100[2]. When comparing EN 13001 to the existing national and industry standards, it becomes clear that this 'new' standard incorporates a different approach to calculating strength and fatigue of cranes.

Since the general approach to fatigue calculation is quite similar in all the existing standards, the differences with EN 13001 are illustrated by comparison with one of these existing standards, namely FEM 1.001. In this white paper, a total of 5 differences between the EN 13001 and the FEM 1.001 will be discussed, namely:

1. Appliance groups vs. stress history parameter (see Section I)
2. Alternating stress vs. stress amplitude (see Section II)
3. Limit state vs. allowable stress method (see Section III)
4. Notch case definition (see Section IV)
5. Introduction of the fatigue-specific resistance factor γ_{mf} (see Section V)

In the following sections, these 5 differences will be evaluated in detail, thus giving an insight into the methodology of the EN 13001 standard.

1) In some sections of this white paper, parts of the text from these standards are used or cited directly in the text.

2) European safety standards are divided into basic safety standards (type A standards), safety group standards (type B1 and B2 standards) and machine-specific standards (type C standards). Type C standards describe significant hazards, specific risks and measures for reducing these risks at special machines or machine types. If a C standard exists for the machine type in question, it takes priority over a B or A type standard.

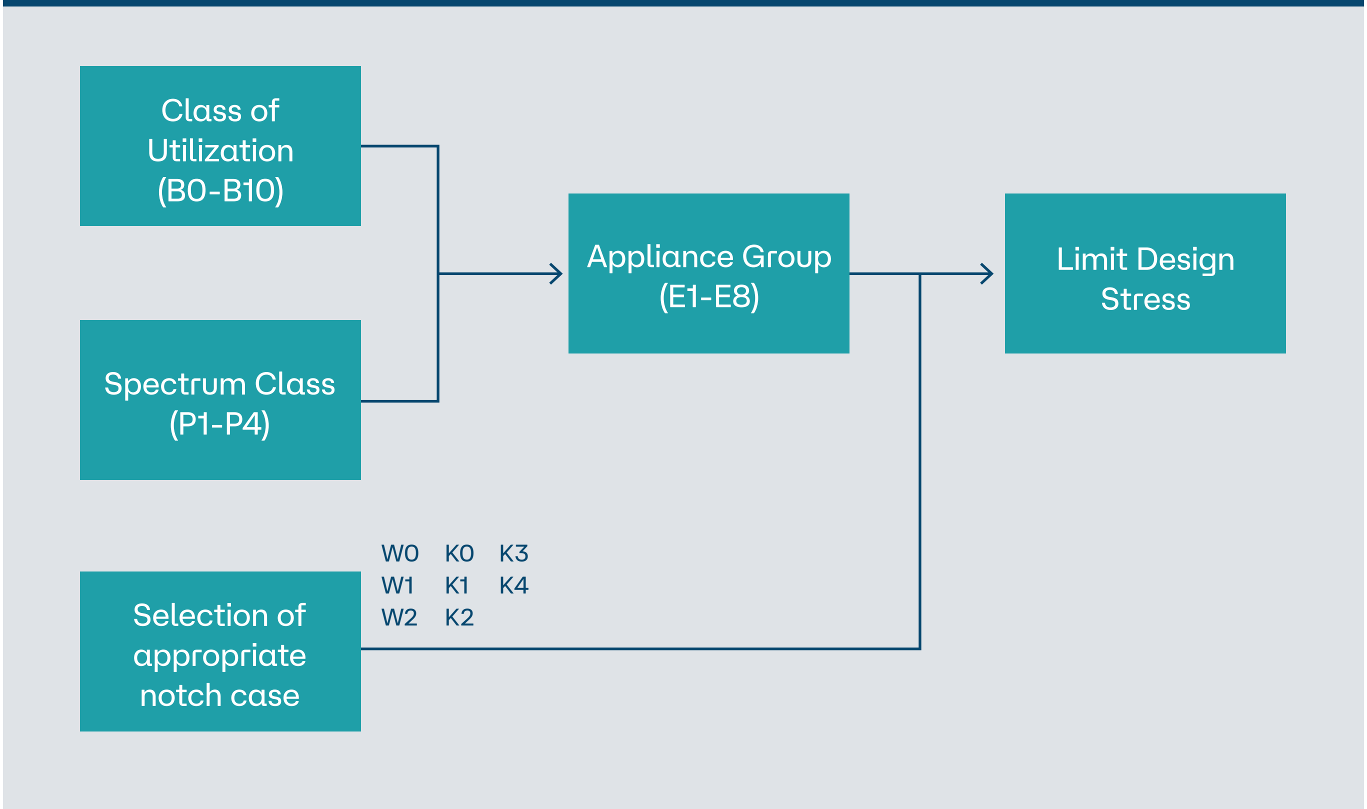
1.0 Appliance groups vs. stress history parameter

Although different on the detailed level of calculation, the general approach to fatigue calculation on cranes was quite similar for all the earlier standards as outlined below.

1. Specification of the amount of hoist cycles (answering the question: how often?), resulting in a Class of Utilization.
2. Specification of the load spectrum (answering the question: how heavy?), resulting in a Spectrum Class.
3. The combination of the answers to 1 and 2 leads to a classification of the crane in an Appliance or Component Group. This results in the use of a general safety factor ('group factor') for the strength calculations and a set of maximum allowable stresses for fatigue[3].
4. For each Appliance or Component Group, the maximum allowable design stresses for fatigue are specified, depending on how well the design detail of the welded connections handles a fatigue load. Three types of unwelded design detail and five classes of welded design detail determine the allowable design stress for fatigue per construction detail.

These four steps in the design process are illustrated in *Figure 1*.

Fig 1: Fatigue calculation according to FEM 1.001



3) The combination of the Class of Utilization and the Spectrum Class in fact forms a very basic way of describing fatigue damage in the steel structure: a low Class of Utilization and a high Spectrum Class can lead to the identical Appliance Group as a higher Class of Utilization and a lower Spectrum Class.

Instead of the classification in Appliance or Component Groups in FEM, EN 13001-3-1 introduces the stress history parameter s_m. The stress history parameter describes the fatigue damage in the material as a one-parameter presentation of stress history during the design life of the crane:

Equation 1

$$s_m = \nu \cdot k_m$$

With:

Equation 2

$$\nu = \frac{N_t}{N_{ref}}$$

And:

Equation 3

$$k_m = \sum \left[\frac{\Delta\sigma_i}{\Delta\hat{\sigma}}\right]^m \cdot \frac{n_i}{N_t}$$

Where:

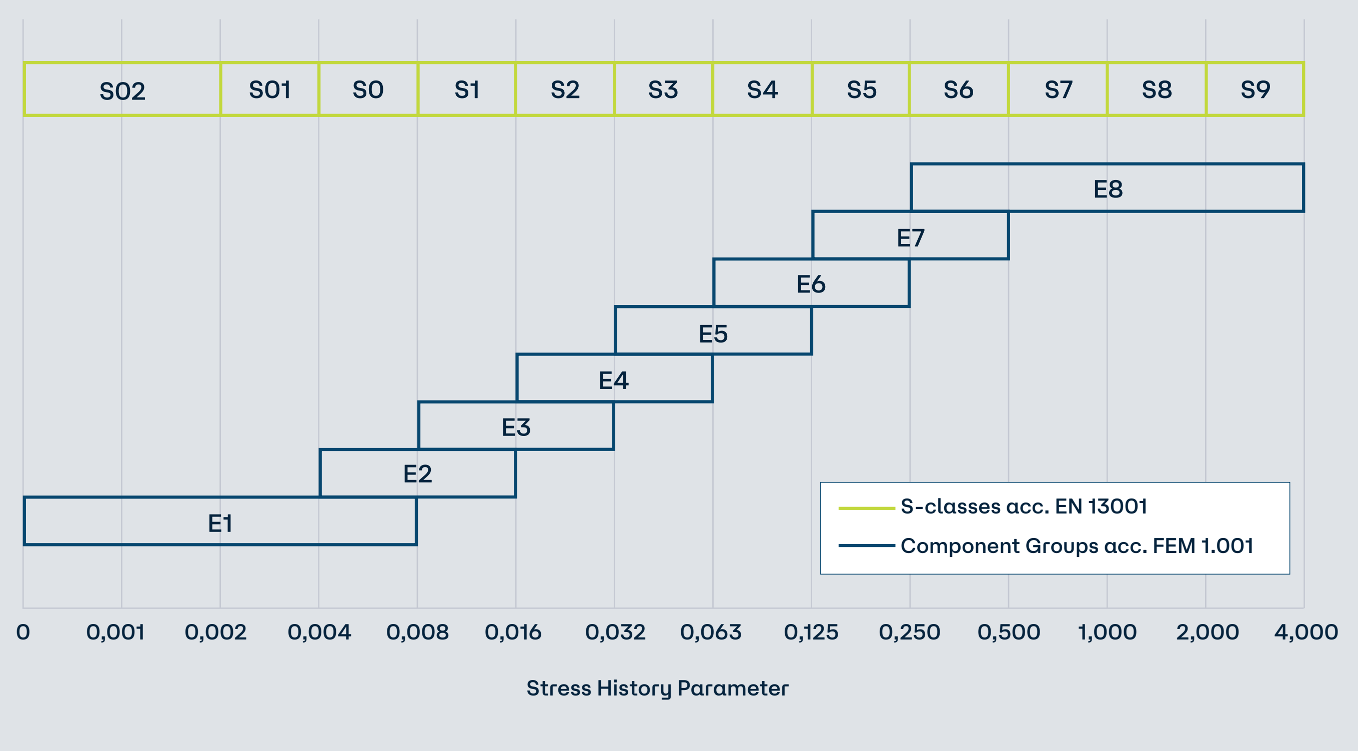
$\nu =$	The relative number of occurrences of stress ranges
$N_t = \sum_i n_i$	The total number of occurrences of stress ranges during the design life of the crane
N_{ref}	The reference number of cycles: $N_{ref} = 2{,}0 \cdot 10^6$ load cycles
k_m	The stress spectrum factor, depending on m
$\Delta\sigma_i$	The stress range i
$\Delta\hat{\sigma}$	The maximum stress range
n_i	The number of occurrences of stress range i
m	The slope constant of the log $\Delta\sigma$ - log N curve of the component under consideration

The stress history parameter s_m has specific values for different points in a structural component. These values are related to crane duty and specifically depend on:

1. The number of working cycles
2. The net load spectrum
3. The crane configuration
4. The effect of the crane motions on stress variations (i.e. crane travelling, trolley travelling and hoisting)

The stress history is characterised by the same value of s_m may be assumed to be equivalent in respect to the damage in similar materials, details or components. ***Figure 2*** shows a comparison between the S-classes in EN 13001 and the Component Groups in FEM 1.001 via the stress history parameter s.

Fig 2: Comparison between the S-Classes in EN 13001 and the Component Groups in FEM 1.001



Thus, the stress history parameter s_m has a similar function as crane groups in the former crane standards such as the FEM 1.001 or the DIN 15018. FEM 1.001 has a total of 8 crane groups where the allowable stresses each have a ratio to the next crane group of 1.3. DIN 15018 has a total of 6 crane groups where the allowable stresses each have a ratio to the next crane group of 1.41.

When calculating fatigue according to EN 13001 with the simplified S-class method, the different S-classes have a ratio of 1.26. However, when the calculation is done by calculating damage accumulation, the stress history parameter in EN 13001-3-1 has a step-less characteristic instead of distinct appliance groups with stepwise decreasing allowable stresses.

2.0 Alternating stress vs. stress amplitude

In order to calculate fatigue, FEM 1.001 and the other conventional standards describe the alternating stress in the material with the ratio $\varkappa$. This ratio is determined by calculating the extreme values of the stresses to which the component is subjected under Case I (fatigue) loadings:

Equation 4

$$\varkappa = \frac{\sigma_{min}}{\sigma_{max}}$$

Where:

σ_{min}	The minimum occurring stress
σ_{max}	The maximum occurring stress

The limit design stress as presented in ***Figure 1*** is based on a 90% probability of survival with a safety coefficient of 4/3. ***Figure 3*** (top: FEM 1.001 Table T.A.3.6.1.) presents these values. Consequently, the allowable stress for a particular member is determined using the calculated value for $\varkappa$ for each crane member. This is illustrated for A52; tension; Group E6 in the bottom part of ***Figure 3*** (FEM 1.001 Figure A.3.6.1).

EN 13001 deals with calculated stress in a different manner. Instead of using a stress alternating coefficient such as $\varkappa$ as described in *Equation 4*, EN 13001 states that the maximum allowable stress range $\Delta\sigma_{Sd}$ should not exceed the limit design stress $\Delta\sigma_{Rd}$:

Equation 5

$$\Delta\sigma_{Sd} \leq \Delta\sigma_{Rd}$$

With:

Equation 6

$$\Delta\sigma_{Sd} = \max(\sigma) - \min(\sigma)$$

Where:

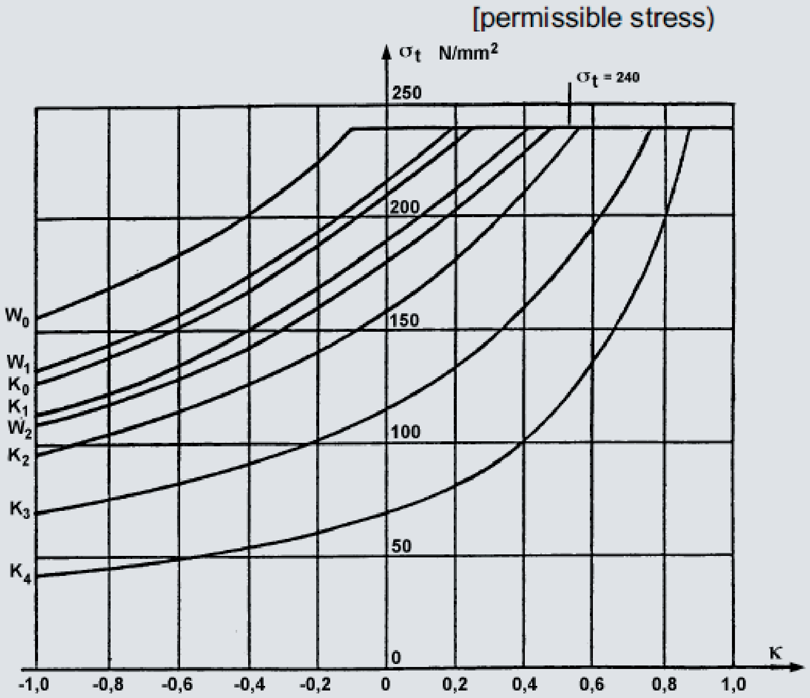
$\Delta\sigma_{Sd}$	Maximum range of the design stress
$\max(\sigma)-\min(\sigma)$	The extreme values of the design stresses, resulting from the calculation
$\Delta\sigma_{Rd}$	Limit design stress

This means that EN 13001 only uses the stress range or amplitude, regardless of whether the stress consists of compression or tensile stress. As a result, the separate check on strength becomes of even greater importance when calculating with the EN 13001 standard, since the fatigue calculation no longer compares the absolute maximum stress with the allowable stress - only the stress range is considered.

Fig 3: FEM 1.001 Table T.A.3.6.1. (top) and Figure A.3.6.1 (bottom)

Table T.A.3.6.1.
Values of σ_W depending on the component group and construction case (N/mm^2)

Component group	Unwelded components Construction cases						Welded components Construction cases (Steels St 37 to St 52, Fe 360 to Fe 510)				
	W_0		W_1		W_2						
	Fe 360 St 37 St 44	St 52 Fe 510	Fe 360 St 37 St 44	St 52 Fe 510	Fe 360 St 37 St 44	St 52 Fe 510	K_0	K_1	K_2	K_3	K_4
E1	249,1	298,0	211,7	253,3	174,4	208,6	(361,9)	(323,1)	(271,4)	193,9	116,3
E2	224,4	261,7	190,7	222,4	157,1	183,2	(293,8)	262,3	220,3	157,4	94,4
E3	202,2	229,8	171,8	195,3	141,5	160,8	238,4	212,9	178,8	127,7	76,6
E4	182,1	201,8	154,8	171,5	127,5	141,2	193,5	172,8	145,1	103,7	62,2
E5	164,1	177,2	139,5	150,6	114,9	124,0	157,1	140,3	117,8	84,2	50,5
E6	147,8	155,6	125,7	132,3	103,5	108,9	127,5	113,8	95,6	68,3	41,0
E7	133,2	136,6	113,2	116,2	93,2	95,7	103,5	92,4	77,6	55,4	33,3
E8	120,0	120,0	102,0	102,0	84,0	84,0	84,0	75,0	63,0	45,0	27,0



Ratio between the extreme stresses
Figure A.3.6.1. - (A 52; tension; group E6)

3.0 Limit state vs. allowable stress method

Another difference between EN 13001 and conventional standards is that calculations are performed according to the Limit State Method. For a general description of this method, reference is made to ISO 2394 ([7]). In the limit state method, individual loads are calculated and where necessary amplified by the applicable dynamic factors, safety factors, and safety coefficients. This has the benefit that each load is accurately amplified by its individual factors.

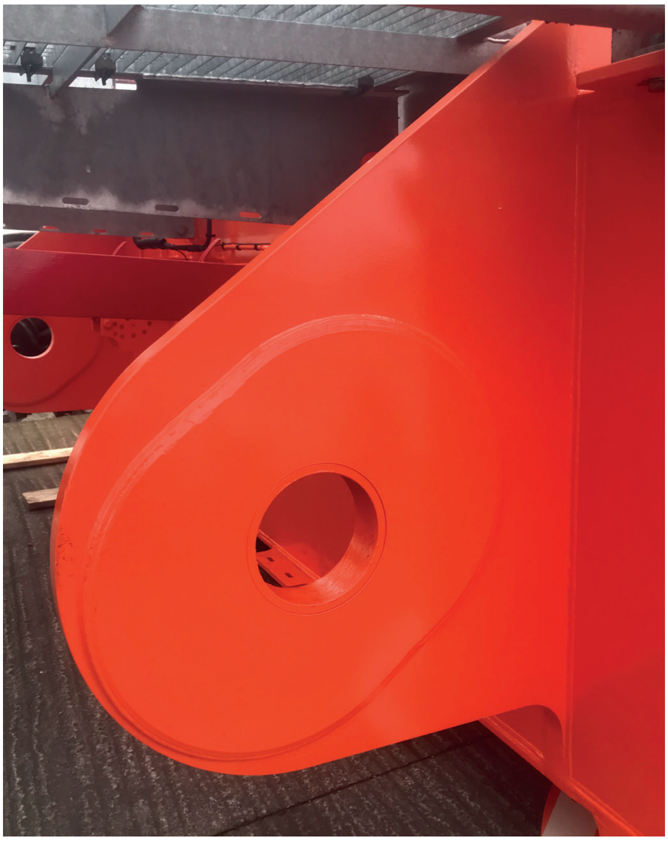
The conventional crane standards such as FEM 1.001 use the Allowable Stress Method, which is a special case of the limit state method. In the allowable stress method, all partial safety factors are given the same value, which combined with the resistance coefficient, forms an overall safety factor. This is illustrated in FEM 1.001 in Section 2.3.1. where all crane loads in the proof of competence[4] are multiplied by an amplifying coefficient (group factor) γ_c, depending on the appliance or component group:

Equation 7

$$\gamma_c\,(S_G + \psi \cdot S_L + S_H)$$

From ***Equation 7*** it is clear that when a higher group factor γ_c is used, this is also applied to the self-weight of the crane "S_G", which is unrealistic because the self-weight of the crane does not change when a crane is subjected to a higher load. In some cases, this method can lead to structures that are too heavy or even to less safe situations, where for example, were counterweights increased by the same factor (see [10]).

It should be noted that the allowable stress method is not prohibited by EN 13001, but is considered a special case of the Limit State Method: According to the EN 13001-1, Section 4.2.7.1, the Allowable Stress Method can be used for the proof of competence. The corresponding safety factors for this approach are given in EN 13001-2, Table 13.



4) In this example, the check on strength in loading Case I is shown, where the appliance is working without wind.

4.0 Introduction of the fatigue specific resistance factor γ_{mf}

Another difference associated with the limit state method is the introduction of the specific resistance coefficient γ_{mf}. After the fatigue stress is calculated with all the applicable factors, the resulting stress is divided by the specific resistance coefficient γ_{mf}. The fatigue strength-specific resistance factor (see ***Figure 4***) is used to account for the uncertainty of fatigue strength values and the possible consequences of fatigue damage. This factor is specified individually for each detail and is applied after the calculation of the fatigue stresses. As seen in ***Figure 4***, the values of γ_{mf} can be quite significant for a crane design, being in the range of:

Equation 8

$$\gamma_{mf} = 1{,}0 \; - \; 1{,}25$$

This means that for construction parts that theoretically comply with the fatigue calculation, but where the detail is not easily accessible for inspection, an additional safety factor of between 1,10 to 1,25 is applicable, depending on the hazard risk for persons and if disassembly is required to gain access to the construction detail. As mentioned in Section 2, FEM 1.001 uses a safety factor of 4/3 on the allowable stress levels.

Fig 4: EN 13001-3-1, Table 9: Fatigue strength specific resistance factor γ_{mf}

Accessibility for inspection	**Fail -safe detail**	**Non fail -safe detail**	
		without hazards for persons	**with hazards for persons**
Detail accessible without disassembly	**1,0**	**1,05**	**1,15**
Detail accessible by disassembly	**1,05**	**1,10**	**1,20**
Non-accessible detail	**N/A**[a]	**1,15**	**1,25**

Fail-safe structural details are those, where fatigue cracks do not lead to the global failure of the crane or dropping load.

Cranes working in protected areas with no access to persons and considered to be without hazards to persons.

Disassembly means that components must be taken apart or dismounted.

A detail is considered to be accessible without disassembly also in cases, where a crack is initiated inside of a closed structure but accessible for detection from outside.

a Non-accessible details shall not be considered to be fail-safe.

b If a risk coefficient $\gamma_n \geq 1{,}2$ is applied, this column may be applied to any non fail-safe detail.

5.0 Notch case definition

FEM 1.001 defines a total of 7 notch cases (3 for unwelded details: W0, W1, and W2 and 4 for welded details: K0, K1, K2, K3, and K4). EN 13001 on the other hand specifies a total of 24 notch cases (NC's). The classification of each of these notch cases is found in EN 13001-3-1, Annex D, and Annex H.

Figure 6, illustrates the 24 NC's as specified in EN 13001 in the top figure and the 7 NC's from the FEM standard in the bottom figure as a function of the stress history parameter (which is related to the Component Group). ***Figure 6*** shows that EN 13001 allows for a much more accurate classification of the welding detail than FEM 1.001. The limit design stress of a construction detail (notch case) is characterised by the value of $\Delta\sigma c$, the characteristic fatigue strength. $\Delta\sigma c$ represents the fatigue strength at 2 x10^6 load cycles under constant stress range loading and with a probability of survival equal to Ps = 97,7% (mean value minus two standard deviations obtained by normal distribution and single-sided test), as illustrated in *Figure 5*. In this figure, m represents the slope constant of the fatigue strength curves[5].

The values for the characteristic fatigue strength $\Delta\sigma c$ (or $\Delta\tau c$ in case of shear stress) and the applicable slope constant m are given in [4], Annex D and H. The welding quality of the detail is to be selected in accordance with EN ISO 5817:2014 [8]. The stresses are calculated in accordance with the nominal stress concept. A nominal stress is the stress in the base material adjacent to a potential crack location.

This is calculated in accordance with simple elastic strength of materials theory, excluding local stress concentration effects. Consequently, according to [4] Section 6.5.2, the limit design stress is calculated as:

Equation 9

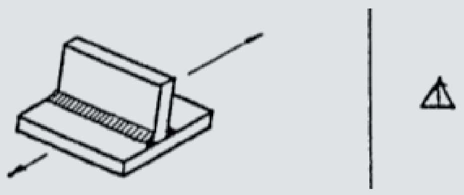
$$\Delta\sigma_{\mathrm{Rd}} = \frac{\Delta\sigma_{\mathrm{c}}}{\gamma_{\mathrm{mf}} \cdot \sqrt[m]{s_m}}$$

Where:

$\Delta\sigma_{\mathrm{Rd}}$	Limit design stress range
$\Delta\sigma_{\mathrm{c}}$	The characteristic fatigue strength
m	The slope constant of the log $\Delta\sigma$ - log N curve (see *Figure 5*)
γ_{mf}	The fatigue strength specific resistance factor (see Section V)
s_m	The stress history factor (Section I)

The comparison of the allowable stresses in welded details raises the question as to which of the standards allows for a higher design stress in a construction detail[6].

K3 Detail



5) m = 3 or 5, depending on the construction detail.

6) There seems to be a tendency in the market where a general statement is made that when recalculating a crane according to the EN 13001, a higher theoretical life time is calculated than with conventional standards. This is not automatically the case: the crane details are calculated more accurately which in some cases can lead to increased longevity, but not in all cases.

As seen in ***Figure 7***, this question does not have a straightforward answer. ***Figure 7*** shows the 'basic' allowable stresses for welded details in Component Group E8 according to the FEM 1.001. Please note that a safety factor of 4/3 is applied to these stress levels. Also illustrated are the allowable stress levels for S-class S7 according to EN 13001 (ref. Table 1) with γ_{mf} = 1,25 (ref. EN 13001-3-1, Table E1). The orange surface shows the cases where in theory a higher design stress is allowed by EN 13001. However, the actual level of both curves depends on the following parameters:

1. For FEM 1.001: the level of the curve is based on the value of ϰ (see Section 2.0) and the Component Group.
2. For EN 13001: the level of the curve is based on the values of γ_{mf} (see Section 4.0) and s (see Section 1.0).

This means that the orange surface can be smaller or bigger, depending on the final level of both curves.

Fig 5: EN 13001-3-1, Figure 8: log Δσ - log N curve

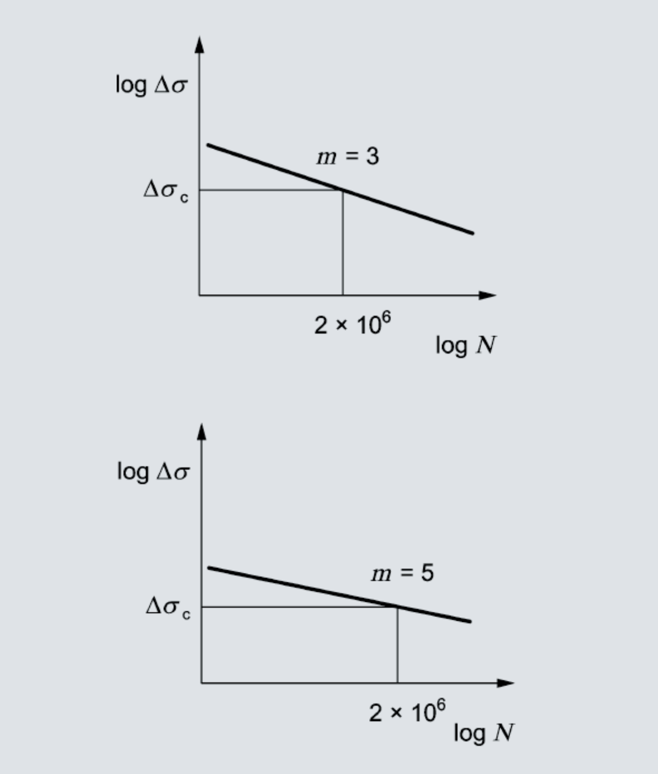


Fig 6: Allowable stress for all NC's as a function of the stress history parameter EN and FEM

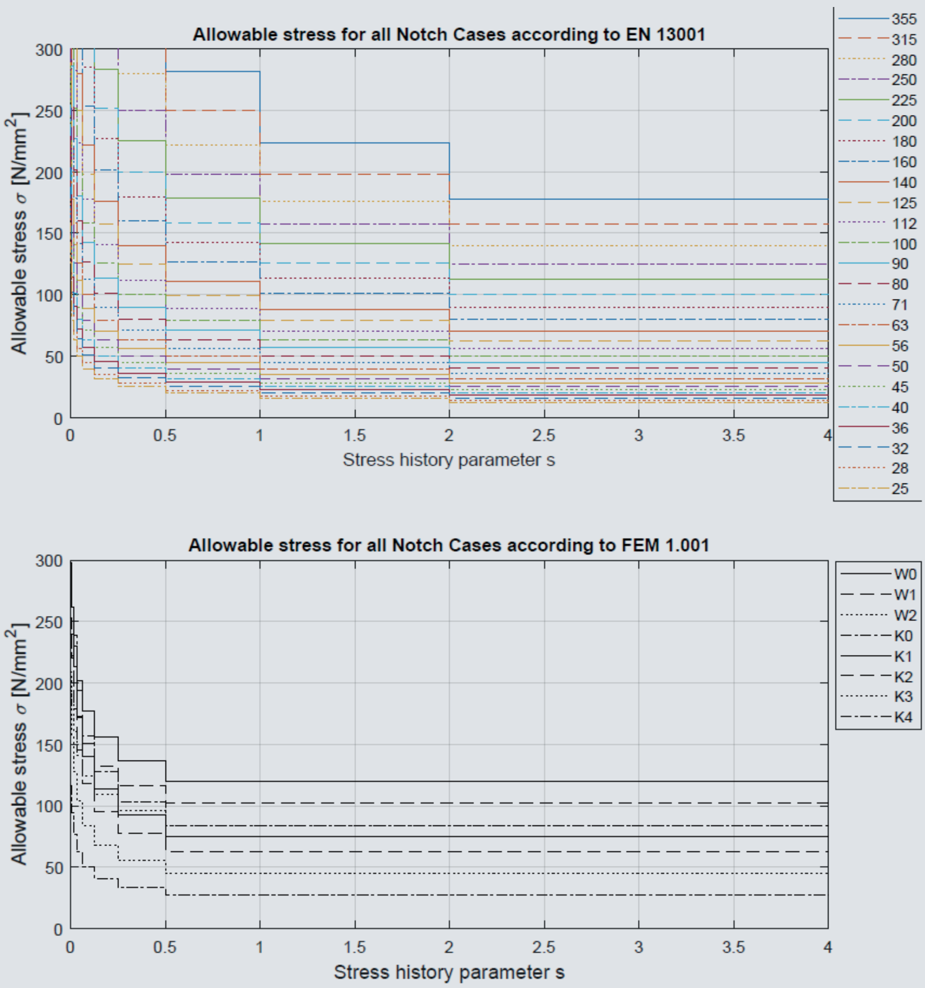
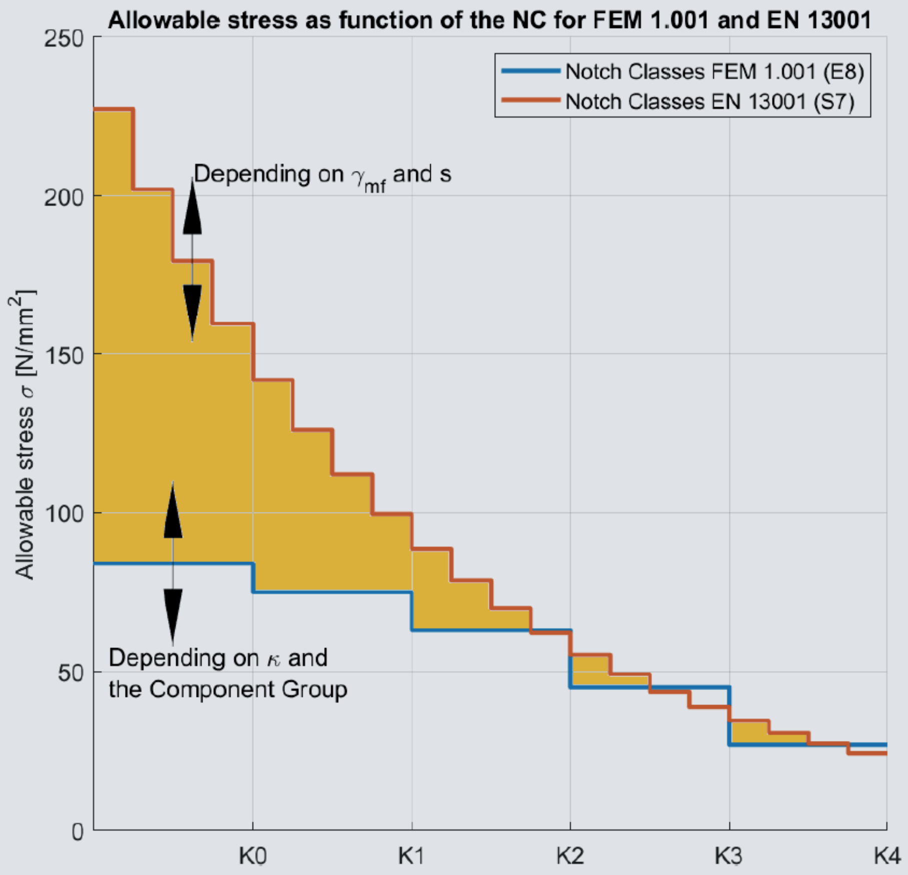


Fig 7: Allowable stress in FEM 1.001 (E8) and EN 13001 (S7)



6.0 Disadvantages of EN 13001

Although the introduction of EN 13001 seems to result in advantages on many sides, such as a more accurate calculation of strength and fatigue, some potential disadvantages are identified when a comparison is made with the traditional standards. It seems that EN 131001 was not specifically written for container cranes. This, as an example, is seen in the use of the dynamic factor $\phi 1$ on the crane mass in EN 13001-2, Section 4.2.2.1 (intended use for slender crane constructions only) as well as for the listed wall thicknesses for welded details of hollow sections (EN 13001-3-1, Table H.1).

1. When using EN 13001, the correct classification of the notch cases for welded structures is essential. In the case where a welded structure is manufactured with a lower welding quality than specified or assumed, the design reserve in conventional standards may, in some cases, be higher than in EN 13001.
2. The same is applicable for the loads: Conventional standards may incorporate a higher design reserve against unintended loads or unintended use of the crane, which as we know sometimes occurs in practice.
3. EN 13001 does not include any classification for mechanisms, such as gearboxes. This means, it only applies to the steel structure of the crane[7].

7) And consequently, a complete container crane including its mechanisms cannot be specified by the EN 13001 standard alone.

Summary

The following can be summarised in the comparison between the FEM 1.001 as a typical conventional standard, and the "new" EN 13001 standard.

Over the last decades, crane design in Europe was regulated by national crane standards, such as the DIN 15018, NEN 2019 on one hand and the FEM 1.001 as the industry standard on the other hand.

Since 2012, a new European crane standard namely EN 13001 is in use. This standard covers a number of topics including the check on the structural strength and fatigue of cranes. This standard is directly linked to the EU Machinery Directive.

EN 13001 has a legal status, and crane manufacturers supplying to the EU and end users in the EU may apply this standard for all new cranes.

Since the approach to the calculation of the steel frame of a crane and to fatigue in particular, is quite different from the existing crane standards, a comparison with the conventional standards is worthwhile. The comparison identifies the impact on crane design, addressing the question, does the application of EN 13001 standard result in different design choices when compared to FEM 1.001 and DIN 15018?

Despite a general perception in the industry that when recalculating a crane according to EN 13001, a higher theoretical lifetime is calculated than with conventional standards, this is not automatically the case. The crane details are calculated more accurately than with conventional standards, which in some cases can lead to increased longevity.

References

[1] FEM 1.001. *Rules for the design of hoisting appliances*, 3rd edition, October 1998.

[2] NEN-EN 13001-1. *Cranes - General design - Part 1: General principles and requirements*, April 2015.

[3] NEN-EN 13001-2. *Crane safety - General design - Part 2: Load actions*, March 2021.

[4] NEN-EN 13001-3-1+A2. *Cranes - General Design - Part 3-1: Limit States and proof competence of steel structure*, January 2018.

[5] DIN 15018. *Krane Grundsätze fur Stahltragwerke*, November 1984.

[6] NEN 2019. *Hijskranen - Het metalen geraamte*, 1st edition, mei 1976.

[7] ISO 2394. *General principles on reliability for structures*, 4th edition, March 2015.

[8] EN ISO 5817:2014. *Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) - Quality levels for imperfections*, February 2014.

[9] Bruno Depale and Mohamed Bennebach. *Residual life of steel structures and equipment: problems and application to cranes*, Mechanics & Industry, September 2020.

[10] Hoist Magazine. *The new way*, 22 November 2005.

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