Crane runway nominal stress fatigue design

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2 Introduction

In this document, nominal stress fatigue design is presented for an exemplary crane-runway. The runway was part of an industrial project, thus it needs to be kept anonymous. Also, dimensions and loads have been slightly modified for this purpose.

The contents of chap. 3 "Practical Example: Crane Runway" was under review and has been revised in the context of SMAR 2026 MS12 [5]. In order to meet the page limits of SMAR 2026, we decided to outsource the detailed analytical calculations for the fatigue analysis into the present document, which will be made available via the home page of the first author.

Related to the reviewed and revised version in [5], minor editorial and formatting changes were made in the present document to adapt as a stand-alone document.

3 Practical Example: Crane Runway

3.1 Geometry and Properties

Each crane bridge is loaded through two trolleys with 6.3 metric tons capacity each, the span of the bridge is 24 m (see Fig. 1 (a)). The closest spacing of the trolleys amounts to 6 m; the trolley near the runway can have a distance of 1 m to the runway. Thus, the mutual center of load of both trolleys is located at a distance of $d = 1.0\text{ m} + 6.0\text{ m} / 2 = 4.0\text{ m}$ off the runway. The load of both trolleys is transferred to $k_1 = (24.0\text{ m} – 4.0\text{ m}) / 24.0\text{ m} = 5/6 = 0.83$ to the near runway and $k_2 = 4.0\text{ m} / 24.0\text{ m} = 1/6 = 0.17$ to the far runway.

Both crane bridges have a wheelbase of 3.80 m. If they are located closest, the minimum wheel distance is 1 m (see Fig. 1 (a)). The crane runway HEB 700 – S235 is 180 m long and runs as continuous beam, the column spacing is 15 x 12,0 m. Main section properties are: flange width 300 mm; flange thickness 32 mm; section modulus W = 7.340 cm³. Since no data from the operator could be given, material is assumed to be RSt 37-2 (DIN 17100:1966) corresponding to S235JR (EN 10025-2:2019). In part, the bottom flange of the runway girder is reinforced by WFL 280x25, which is not used in the following example calculations.

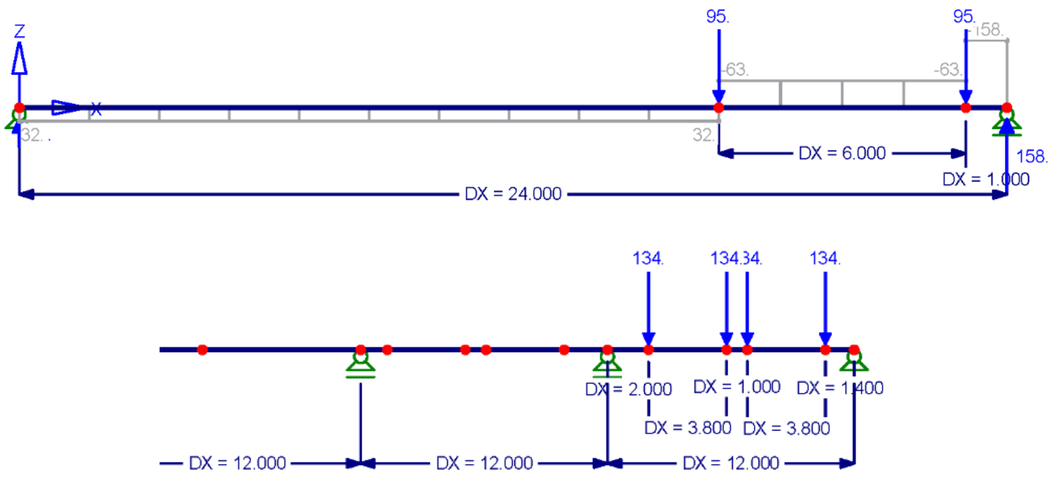

Figure 1. Structural system of example crane;
dimensions in [m]; loads and support reactions in [kN]
(a) elevation of crane bridge with trolley loads (self weight + pay load) closest to right runway;
without self weight of crane bridge;
support reactions of the bridge are sum of two wheel loads; grey: distribution of shear forces;
(b) elevation of end of crane runway;
position of wheel loads from two bridges is governing for max bending moments
in the end bay and at the first intermediate support.

3.2 Loads

Nominal (max) loads: 32 kN self weight and 63 kN pay load per trolley; total 95 kN

Load proportion on the adjacent crane runway:

$$32\ \text{kN} \cdot 0.83 = 27\ \text{kN}; \quad 63\ \text{kN} \cdot 0.83 = 52\ \text{kN}; \quad \text{total } 79\ \text{kN}$$

Load proportion on the far runway:

$$32\ \text{kN} \cdot 0.17 = 5\ \text{kN}; \quad 63\ \text{kN} \cdot 0.17 = 11\ \text{kN}; \quad \text{total } 16\ \text{kN}$$

calculatory, each trolley is loading one wheel of the crane bridge

Self weight of bridge 220 kN, i.e. 55 kN per wheel;

Crane bridge with loaded trolleys on the near side, load per wheel: 55 kN + 79 kN = 134 kN

Crane bridge with empty trolleys on the near side, load per wheel: 55 kN + 27 kN = 82 kN

Crane bridge with empty trolleys on the near side, load per wheel: 55 kN + 5 kN = 60 kN

Wheel loads with empty trolley are at minimum 60 kN / 134 kN = 0.45 of full trolley wheel loads; but counted lifts can be with bridge positions far away from end bay or first intermediate column. This justifies choice of spectrum S_0 taken from DIN 15018-1 [2] (see Fig. 3 (a)), which corresponds to counted lifts with zero loads.

The stress resultants for governing positions of bridges and trolleys under nominal loads are

end bay	+750 kNm and –150 kNm;	ΔM = 900 kNm
1st intermediate column:	–475 kNm and +15 kNm;	ΔM = 490 kNm

3.3 Frequency

The frequency of trolley / crane bridge operation (data could not be provided by the operator) is estimated as follows: Note, that this is on the safe side, because the bridges are not located in the end bay with every lift; also, the trolleys are not located adjacent to the runway with every counted lift. Thus, the frequency of crane operation is a generous upper bound for the load cycles for a considered position of the runway.

1. 10 cycles per hour (i.e. 1 cycle per 6 minutes); could be much more for a short time (loading or unloading a truck); but after that, there are halting times over the day

2. 12 hours per working day (corresponding to 1.5 shifts); could be less

3. 250 working days per year (i.e. 50 weeks of 5 working days each); there could be Saturday working

4. 50 years of operating life time (runway is built app. 1972)

With these assumptions we receive:

$N_{\text{year}} = 10 \cdot 12 \cdot 250 = 30{,}000; \quad N_{50\text{y}} = 30{,}000 \cdot 50 = 1.5\ \text{mil}$

3.4 Notch details

Classification acc. to EN 1993-1-9 [4]:

- Double clamp, see Fig. 2 (a); length in loading direction 130 mm;
  FAT (fatigue detail category) 56 (Tab. 8.4 No. 1)

- Anti-tipping stiffener's flange, see Fig. 2 (b); length in loading direction 140 mm;
  FAT 56 (Tab. 8.4 No. 1)

Figure 2. (a) Crane runway top flange welded-on rail double-clamp (photo IPU/pk 2022);
(b) Anti-tipping stiffener T140 (photo IPU/cs 2022);
top end of (b) with cracked weld (photo IPU/pk 2022).

3.5 Calculatory fatigue life

3.5.1 Nominal stresses

Nominal stresses under max stress resultants, see 3.2:

End bay, upper flange: σ = +150 kNm / 7.340 cm³ = +20 MPa
σ = –750 kNm / 7.340 cm³ = –102 MPa compr. prevailing
$\Delta\sigma$ = +20 MPa – (–102 MPa) = 122 MPa

direct evaluation for plausibility check: $\Delta\sigma$ = 900 kNm / 7.340 cm³ = 123 MPa q.e.d.

End bay, lower flange: same numbers with different sign tension prevailing

First intermed. column, upper fl. σ = +475 kNm / 7.340 cm³ = +65 MPa tension prevailing
σ = –15 kNm / 7.340 cm³ = –2 MPa
$\Delta\sigma$ = +65 MPa – (–2 MPa) = 67 MPa

direct evaluation for plausibility check: $\Delta\sigma$ = 490 kNm / 7.340 cm³ = 67 MPa q.e.d.

First intermediate column, lower fl. same numbers with different sign compression prevailing

3.5.2 EN 1991-3 approach

Selected hoisting class HC and S-class: warehouse crane with discontinuous operation:

HC2 with S4, intermediate parameters λ and φ acc. EN 1991-3 [3].

$\Delta\sigma_{equ}$ is the damage-equivalent stress range for a one-stage-spectrum.

$\lambda = 0.500$ (Tab. 2.12); $\varphi_1 = 1.0$ (Tab. 2.4); $\varphi_{2,min} = 1.10$ (Tab. 2.5);

$\varphi_{fat,1} = (1 + \varphi_1) / 2$; $\varphi_{fat,1} = (1 + 1.00) / 2 = 1.00$ (eq. 2.19)

$\varphi_{fat,2} = (1 + \varphi_2) / 2$; $\varphi_{fat,2} = (1 + 1.10) / 2 = 1.05$ (eq. 2.19)

Note: When investigating damage equivalent load factors λ in a study on bridges it was found, that in some cases results were unconservative (Schillinger (2017); Kraus and Geißler (2026)). Thus, if in doubt, more direct methods like Palmgren-Miner approach should be used (see sect. 3.5.4), even if these require more effort.

Fatigue load factor k_{fat} taken from eq. 2.16: $k_{fat} = \varphi_{fat} \cdot \lambda = 1.05 \cdot 0.500 = 0.53$;

Equivalent stress range for 2 mil cycles:

Top + bottom flange in end bay: $\Delta\sigma_{\text{equ}} = \Delta\sigma \cdot k_{\text{fat}} = 123\ \text{MPa} \cdot 0.53 = 65\ \text{MPa}$

Top + bottom flange at 1st intermediate column: $\Delta\sigma_{\text{equ}} = \Delta\sigma \cdot k_{\text{fat}} = 67\ \text{MPa} \cdot 0.53 = 36\ \text{MPa}$

Remark: In EN 1993-1-9 [4], full mean-stress independence is assumed. Thus, the stress range Δσ is considered only.

Utilization η based on the FAT class determined in sect. 3.4:

End bay: $\eta = 65\ \text{MPa} / 56\ \text{MPa} = 1.16$

1st intermediate column: $\eta = 36\ \text{MPa} / 56\ \text{MPa} = 0.64$

For further discussion on the results of this approach see sect. 3.5.5.

3.5.3 DIN 4132 / DIN 15018 approach

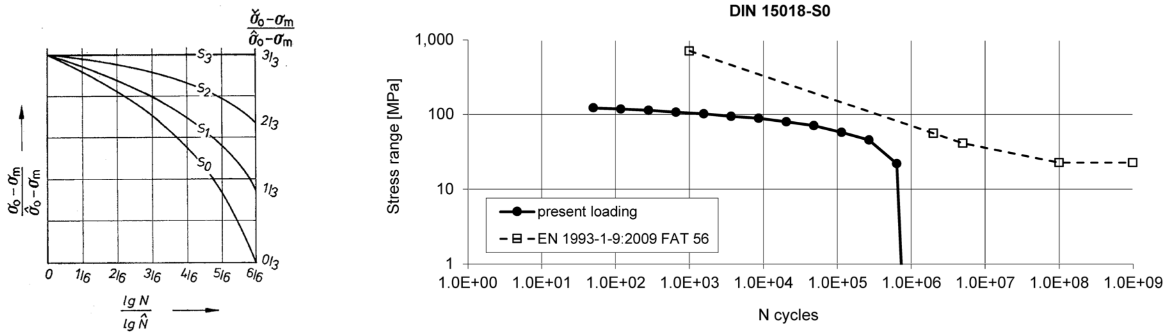

Figure 3. (a) Standardized semi-log stress spectra given in DIN 15018-1 [2] Fig. 8;
(b) Double-log stress spectrum S_0 taken from DIN 15018-1 [2] with $\Delta\sigma$ = 122 MPa;
N_{total} = 1.5 mil cycles; S-N curve (stress-number curve; Wöhler curve) from EN 1993-1-9 [4]
for detail category FAT 56.

Approach according to DIN 4132 [1] with a standardized spectrum taken from DIN 15018-1 [2]. In DIN 4132 [1], mean-stress independence is not assumed. Thus, stress magnitude and relation of extreme stresses κ (kappa) need to be considered.

The relation of extreme stresses amount to (smaller to larger stress), see sect. 3.5.1:

$\kappa_{bay,topflange}$ = +20 MPa / –102 MPa = –0.20

$\kappa_{bay,bottomflange}$ = –20 MPa / +102 MPa = –0.20

The life-time cycles estimated in sect. 3.3, correspond to number-of-cycles-range N3 in Tab. 20. With an assumed stress-spectrum of S_0 (see Fig. 3 (a)), this leads to stress stage B3.

Detail category acc. DIN 4132 [1] Tab. 6 No. 441: K4 (extra severe notch)

Admissible upper stress acc. DIN 4132 [1] Tab. 3 Line 1 for κ = –1; for B3: σ_{adm} = 76.4 MPa

Admissible upper tensile stress for alternating stresses acc. DIN 4132 [1] Tab. 3 Line 3

$$\sigma_{\text{adm;tensile;}\kappa<0} = \frac{5}{3-2\kappa} \cdot \sigma_{\text{adm;}\kappa=-1} \quad (1)$$

$$\sigma_{\text{adm;tensile;}\kappa=-0{,}20;\text{B3}} = \frac{5}{3-2\cdot(-0{,}20)} \cdot (+76.4\ \text{MPa}) = 1.47 \cdot (+76.4\ \text{MPa}) = +112\ \text{MPa} \quad (2)$$

Admissible upper compressive stress for alternating stresses acc. DIN 4132 [1] Tab. 3 Line 3

$$\sigma_{\text{adm;compr.;}\kappa<0} = \frac{2}{1-\kappa} \cdot \sigma_{\text{adm;}\kappa=-1} \quad (3)$$

$$\sigma_{\text{adm;compr.;}\kappa=\text{ -0,20;B3}} = \frac{2}{1-(-0{,}20)} \cdot (-76.4\ \text{MPa}) = 1.67 \cdot (-76.4\ \text{MPa}) = -127\ \text{MPa} \quad (4)$$

Utilization based on upper stress level as given in sect. 3.5.1:

End bay, upper flange B3 η = –102 MPa / (–127 MPa) = 0.80

End bay, lower flange B3 η = +102 MPa / (+112 MPa) = 0.91

For further discussion on the results of this approach see sect. 3.5.5.

3.5.4 Palmgren-Miner approach acc. EN 1993-1-9

Damage accumulation acc. EN 1993-1-9 [4] eq. A.1 and Fig. A.1, based on spectrum S_0 given in DIN 15018-1 [2] Fig. 8, see Fig. 3 (a), and the stress range given in sect. 3.5.1.

A year spectrum was defined with 30,000 cycles, see sect. 3.3, which is run 50 times (years). This implies that the max stress range occurs once a year, so that the curve of present loading starts at N = 50, see Fig. 3 (b).The damage sum D amounts to D = 0.14, see Tab. 1. A graphical representation is given in Fig. 3 (b). Please note that the shapes of the spectra S_0 in Fig. 3 (a) and Fig. 3 (b) are looking different. This is because Fig. 3 (a) is semi-logarithmic, while Fig. 3 (b) is logarithmic on both axes.

A damage sum of D = 1.00 is achieved, if the stress range is increased to 229 MPa (not documented here in detail).

Utilization based on stress range as given in sect. 3.5.1:

End bay, upper and lower flange η = 122 MPa / 229 MPa = 0.53

For further discussion on the results of this approach see sect. 3.5.5.

Note, that if the spectrum was defined “in one piece”, i.e. one „package” for 1.5 mil cycles, lesser of the big stress ranges would be counted in the damage sum. Thus, the damage sum would be reduced to D = 0.06 (not documented here in detail).

Table 1. Evaluation of the damage sum according to Palmgren-Miner, see Fig. 3;
stress spectrum S_0 taken from DIN 15018-1 [2] with $\Delta\sigma$ = 122 MPa; N_{total} = 1.5 mil cycles;
S-N curve from EN 1993-1-9 [4] for detail category FAT 56;
the damage sum amounts to D = 0.14.

			spectrum			service life		Palmgren-Miner		
i	$\sigma_{upper,ref}$ [MPa]	$\sigma_{upper,norm}$ [MPa]	$\Delta\sigma$ [MPa]	Σ n_i normalized log N / log N_{hat}	Σ n_i absolute	$n_{E,i}$	Σ $n_{E,i}$	$N_{R,i}$	$D_i = n_{E,i} / N_{R,i}$	Σ D
1	61.0	1.000	122.0	0.000	1	50	50	1.93E+05	0.000	0.000
2	61.0	0.960	117.1	0.083	2	68	118	2.19E+05	0.000	0.001
3	61.0	0.927	113.1	0.167	6	161	279	2.43E+05	0.001	0.001
4	61.0	0.870	106.1	0.250	13	379	658	2.94E+05	0.001	0.003
5	61.0	0.836	102.0	0.333	31	896	1,554	3.31E+05	0.003	0.005
6	61.0	0.770	93.9	0.417	73	2,114	3,668	4.24E+05	0.005	0.010
7	61.0	0.723	88.2	0.500	173	4,992	8,660	5.12E+05	0.010	0.020
8	61.0	0.650	79.3	0.583	409	11,786	20,447	7.04E+05	0.017	0.037
9	61.0	0.576	70.3	0.667	965	27,828	48,274	1.01E+06	0.027	0.064
10	61.0	0.470	57.3	0.750	2,280	65,701	113,975	1.86E+06	0.035	0.099
11	61.0	0.372	45.4	0.833	5,382	155,119	269,094	3.76E+06	0.041	0.141
12	61.0	0.180	22.0	0.917	12,707	366,234	635,328	1.00E+50	0.000	0.141
13	61.0	0.000	0.0	1.000	30,000	864,672	1,500,000	1.00E+50	0.000	0.141

3.5.5 Calculatory fatigue life results

Obviously, the results for the end bay upper flange given in sections 3.5.2, 3.5.3 and 3.5.4 are ambiguous.

EN 1991-3 [3]	see sect. 3.5.2; spectrum defined by HC2/S4	η = 1.16
DIN 4132 [1] / DIN 15018-1 [2]	see sect. 3.5.3; spectrum defined by S_0/B3	η = 0.80
EN 1993-1-9 [4] Palmgren-Miner	see sect. 3.5.4; spectrum defined by S_0	η = 0.53

Note: partial safety factors are not considered.

Acc.to EN 1991-3 [3], a crack should be expected in the end bay, which was not conformed on site, since cracks between the rail clamps and the upper flange of the runway beam (see Fig. 2) were not found. In comparison, the Palmgren-Miner approach yields results which are more optimistic by a factor of 2.2, which matches the findings on site.

The main reasons for these discrepancies are – apart from the different approaches inherent in the codes:

– The operator could not provide the data needed. At best, a hoisting history of each trolley along with the respective position of the trolley on the crane bridge and the associated position of the crane bridge on the runway would be needed. However, in practice, this data is not recorded for older cranes.

- In absence of the data needed, very rough assumptions are required, which bear big uncertainties. Classification HC2/S4 might be pessimistic for a “warehouse crane with discontinuous operation”.

- According to the experience of the authors, a similar situation is encountered in all projects, where the assessment of cracked steel components is asked.

On the other hand, a cracked weld between the upper flange and the anti-tipping stiffener above a support was documented, see Fig. 2. There, the range of longitudinal stresses in the flange is only 55 % of those in the end bay, which makes the crack in the weld even harder to explain.

4 Summary

In the present document, analytical fatigue checks for an exemplary crane runway are presented. In order to demonstrate the uncertainty involved in this procedure, three different approaches were used. The range of utilization found is given in sect. 3.5.5.

5 References

[1] DIN 4132: Kranbahnen. Stahltragwerke; Grundsätze für Berechnung, bauliche Durchbildung und Ausführung sowie Beiblatt 1. Februar 1981. (withdrawn)

[2] DIN 15018: Cranes. Principles for steel structures.
Part 1: Stress analysis. November 1984. (withdrawn)

[3] EN 1991 (EC1): Actions on structures.
Part 3: Actions induced by cranes and machinery. 2006 + AC:2013.

[4] EN 1993 (EC3): Design of steel structures.
Part 1-9: Fatigue. 2005 + AC:2009.

[5] Knoedel, P., Gkatzogiannis, S., Hörenbaum, C.: Dealing with Fatigue Cracks in Steel Components. Paper accepted, full paper 954 (revised version) submitted as of 03 June 2026. Mini-Symposium 12, SMAR 2026, 8th International Conference on Smart Monitoring, Assessment and Rehabilitation of Civil Structures, Dresden, Germany – August 26–28, 2026.