

# Metal Structures II

## Lecture II

### Crane supporting structures

#### Loads

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## General information about loads

There are four types of interaction crane - structure



Photo: spawstal.pl



Photo: eci.com.pl

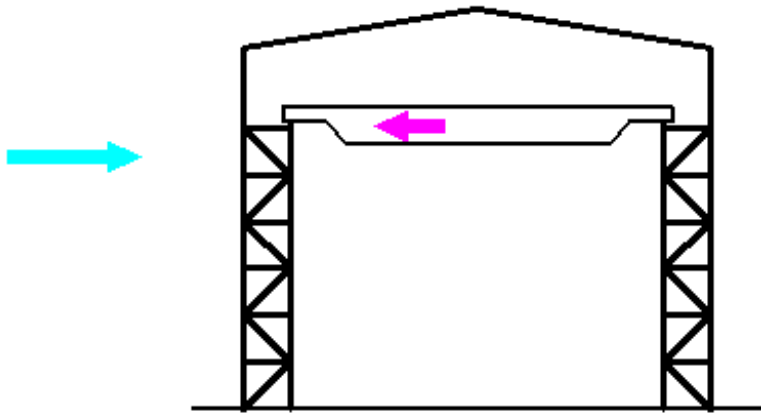


Photo: hak.com.pl

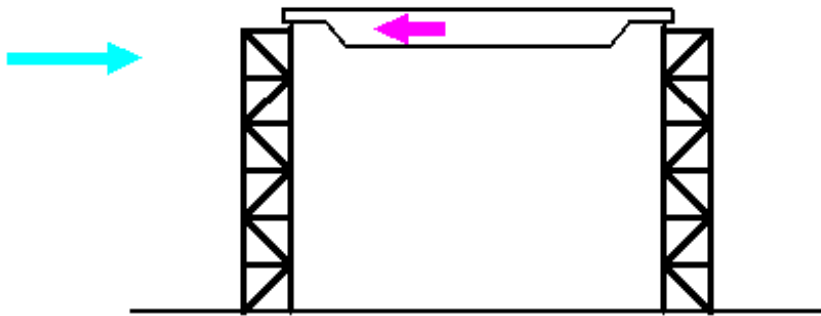
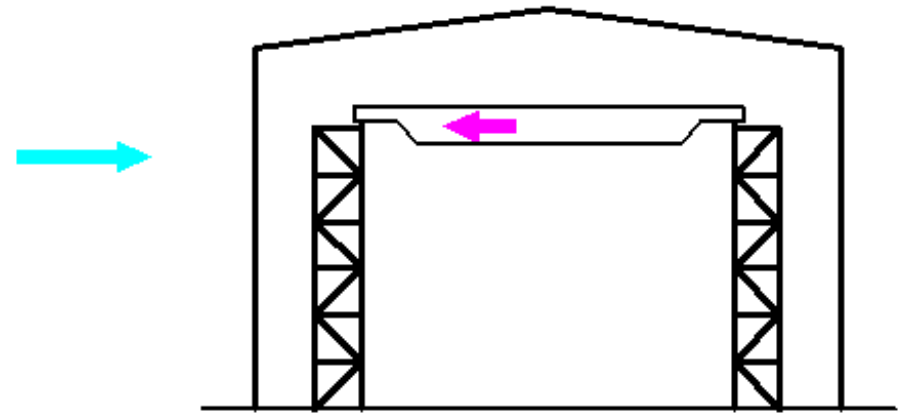


Photo: budus.edu.pl

A

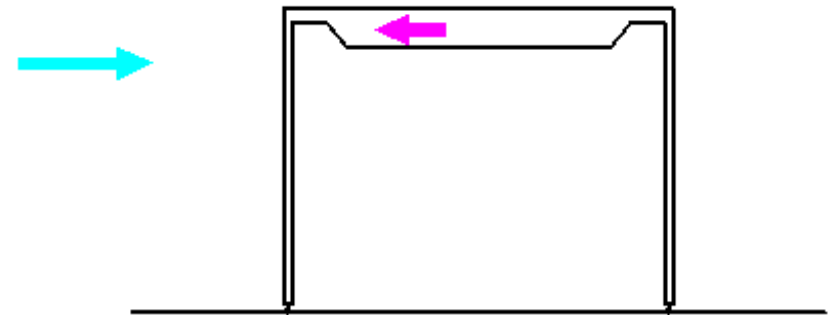


B



C

Photo: Author



D

Case	Crane supporting structure	Hall structure
A	Dead weight Climatic actions Crane actions	
B	Dead weight Crane actions	Dead weight Climatic actions
C	Dead weight Climatic actions Crane actions	Not exists
D	Not exists	

## EN 1991 Actions on structures (common name: Eurocode 1)

### 1991-1 General actions:

1991-1-1 Densities, self-weight, imposed loads for buildings

1991-1-2 Actions on structures expose to fire

1991-1-3 Snow loads

1991-1-4 Wind actions

1991-1-5 Thermal actions

1991-1-6 Actions during execution

1991-1-7 Accidental actions

1991-2 Traffic loads on bridges

1991-3 Actions induced by cranes and machinery

1991-4 Silos and tanks

There are three possibilities of loads from crane:

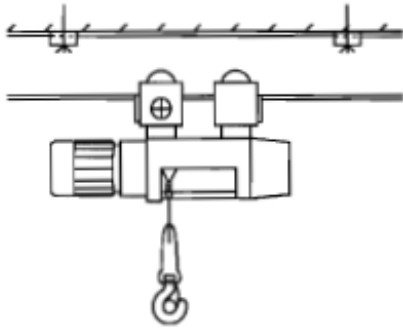
Monorail hoist block

Overhead travelling crane:

underslung crane

top-mounted crane

Photo: EN 1991-3 fig.1.2



Monorail hoist block

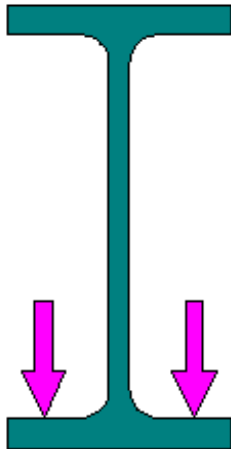
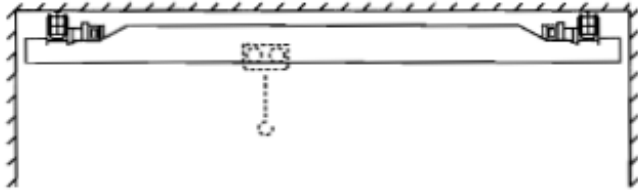


Photo: Author

Photo: eurotech-opole.pl



Photo: EN 1991-3 fig.1.3



## Overhead underslung crane

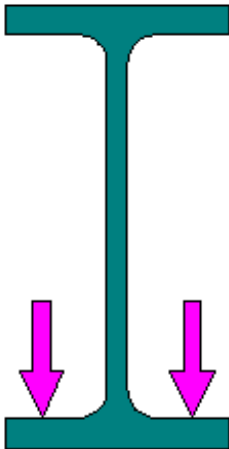
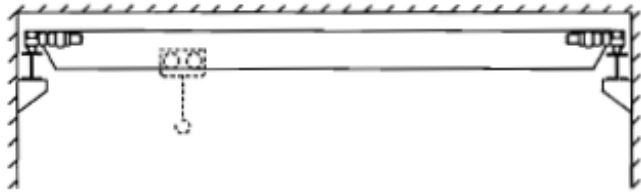


Photo: Author

Photo: spkozyczkowo.edupage.org

Photo: EN 1991-3 fig.1.4



Overhead top-mounted crane



Photo: Author



Photo:promag.pl



Dead weight of monorail hoist block  $\ll$  dead weight of crane

Dead weight of monorail hoist block  $\approx$  crab of crane

Number of combinations of load (monorail)  $\ll$  number of combinations of load (crane)

Many types of crane actions have dynamic character. There are special calculation for this case:

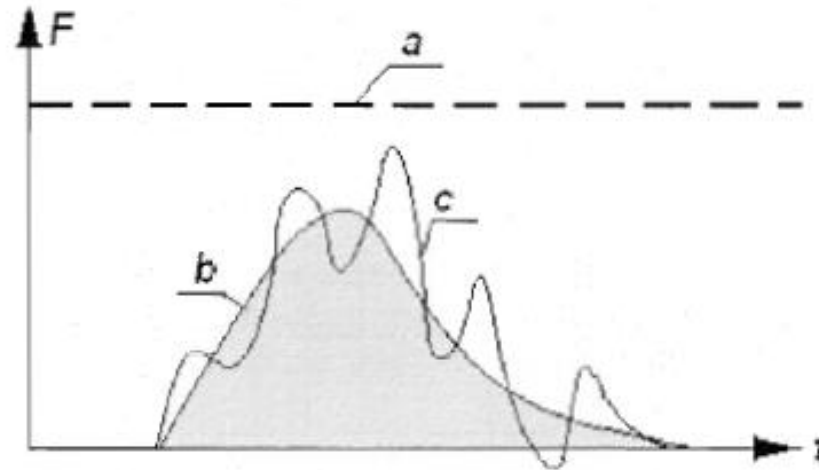


Photo: EN 1991-1-7 fig. 1.1

Key :  
a : equivalent static force  
b : dynamic force  
c : structural response

$$F_{\varphi,k} = \varphi_i F_k$$

$F_k$  – equivalent dynamic force;  $\varphi_i$  – dynamic coefficient;  $F_{\varphi,k}$  – equivalent static force

Dynamic factors	Effect to be considered	To be applied to
$\varphi_1$	Excitation of the crane structure due to lifting the hoist load off the ground	Self-weight of the crane
$\varphi_2$ or $\varphi_3$	Dynamic effects of transvering the hoist load from the ground to the crane  Dynamic effects of sudden release the payload if for examble grabs or magnet are used	Hoist load
$\varphi_4$	Dynamic effects induced when the crane is travelling on rail tracks or runways	Self-weight of the crane and hoist load
$\varphi_5$	Dynamic effects caused by drive forces	Drive forces
$\varphi_6$	Dynamic effects of a test load moved by the drivers in the way the crane is used	Test load
$\varphi_7$	Dynamic elastic effect of impact on buffers	Buffer loads

EN 1991-3 tab. 2.1

		Symbol	Section	Groups of load									
				ULS							Test load	Accidental loads	
				1	2	3	4	5	6	7			
1	Self-weight of crane	$Q_c$	2.6	$\varphi_1$	$\varphi_1$	1	$\varphi_4$	$\varphi_4$	$\varphi_4$	1	$\varphi_1$	1	1
2	Hoist load	$Q_h$	2.6	$\varphi_2$	$\varphi_3$	0	$\varphi_4$	$\varphi_4$	$\varphi_4$	$\eta$	0	0	0
3	Acceleration of crane bridge	$H_L$ $H_T$	2.7	$\varphi_5$	$\varphi_5$	$\varphi_5$	$\varphi_5$	0	0	0	$\varphi_5$	0	0
4	Skewing of crane bridge	$H_S$	2.7	0	0	0	0	1	0	0	0	0	0
5	Acceleration of barking of crab or hoist block	$H_{T3}$	2.7	0	0	0	0	0	1	0	0	0	0
6	In-service wind	$F_W^*$	Annex A	1	1	1	1	1	0	0	1	0	0
7	Test load	$Q_T$	2.10	0	0	0	0	0	0	0	$\varphi_6$	0	0
8	Buffer force	$H_B$	2.11	0	0	0	0	0	0	0	0	$\varphi_7$	0
9	Tilting force	$H_{TA}$	2.11	0	0	0	0	0	0	0	0	0	1

For out of service wind, see Annex A

$\eta$  is the proportion of the hoist load that remains when payload is removed, but is not included in the self-weight of the crane

EN 1991-3 tab. 2.2

Only forces, acts from crane on STR ULS are presented in table 2.2.:

Self-weight of crane,  $\varphi_1 \rightarrow \#t / 26$

Hoist load,  $\varphi_2 \rightarrow \#t / 27 - 28$

$\varphi_3 \rightarrow \#t / 29$

$\varphi_4 \rightarrow \#t / 30$

$\eta \rightarrow \#t / 31$

Acceleration of crane bridge,  $\varphi_5 \rightarrow \#t / 32 - 38, 45 - 46$

Skewing of crane bridge  $\rightarrow \#t / 39 - 46$

Acceleration of barking of crab or hoist block  $\rightarrow \#t / 47 - 48$

Wind actions  $\rightarrow \#t / 49 - 56$

Test load,  $\varphi_6 \rightarrow \#t / 57$

Buffer force,  $\varphi_7 \rightarrow \#t / 58 - 61$

Tilting force  $\rightarrow \#t / 62 - 63$

There are separated rules for monorail hoist block.

Additionally, there must be taken into consideration actions:  
from workers on walkways, stairs, platforms and guardrails;  
for FAT ULS;  
for SLS.

Monorail hoist block → #t / 64

Workers activity → #t / 65

Fatigue actions → #t / 66 - 78

SLS → #t / 79

## Types of wheels

There are three types of crane wheels: no flange, one side flange, two sides flange wheel

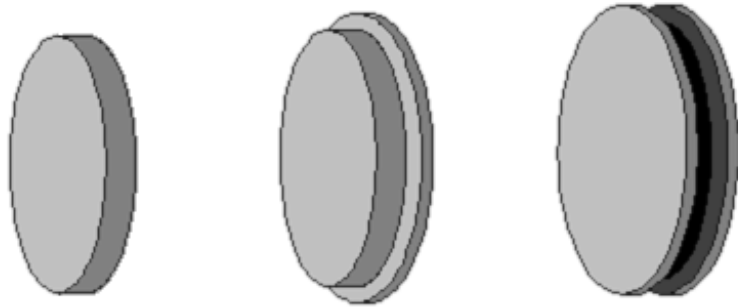


Photo: Author



Photo: windexholding.pl



Photo: dgcrane.com



Photo: i.ebayimg.com



Second type of guidance means, dedicated for cranes with no flange wheels, is roller guide. It should be used for one side flange wheels. It is pair of horizontal wheels on both sides of rail.



Photo: voith.at

Flange or not flange wheels are important for calculation of analysis horizontal loads, act from crane on rails, runbeams and supported structure.

Generally, horizontal contact wheels-rail and transport of horizontal loads from crane to runbeams exists for both runbeams, because of friction between wheel and rails.

Transport of horizontal loads from crane to runbeams is possible only when horizontal force is not greater than friction force ( $\mu \rightarrow \#t / 37$ ).

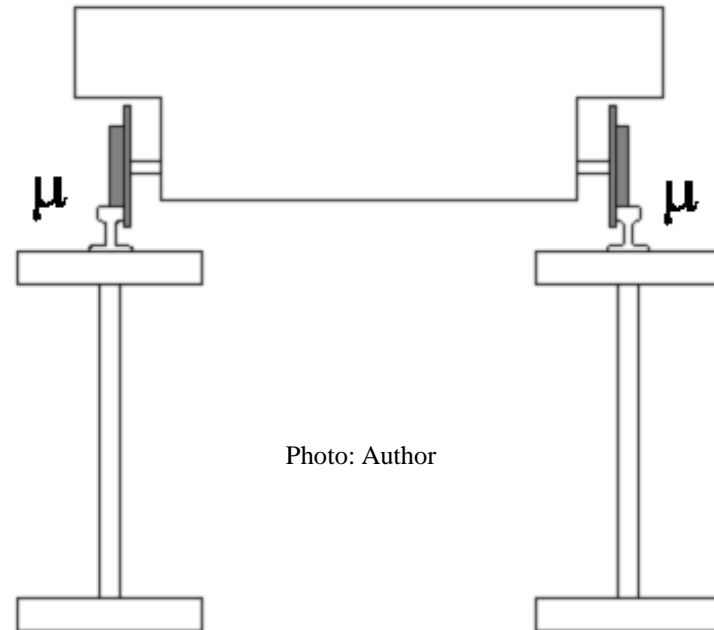


Photo: Author

One side flange wheel - theoretically, horizontal contact wheels-rail and transport of horizontal loads from crane to runbeams is possible only for wheels on one side of crane.

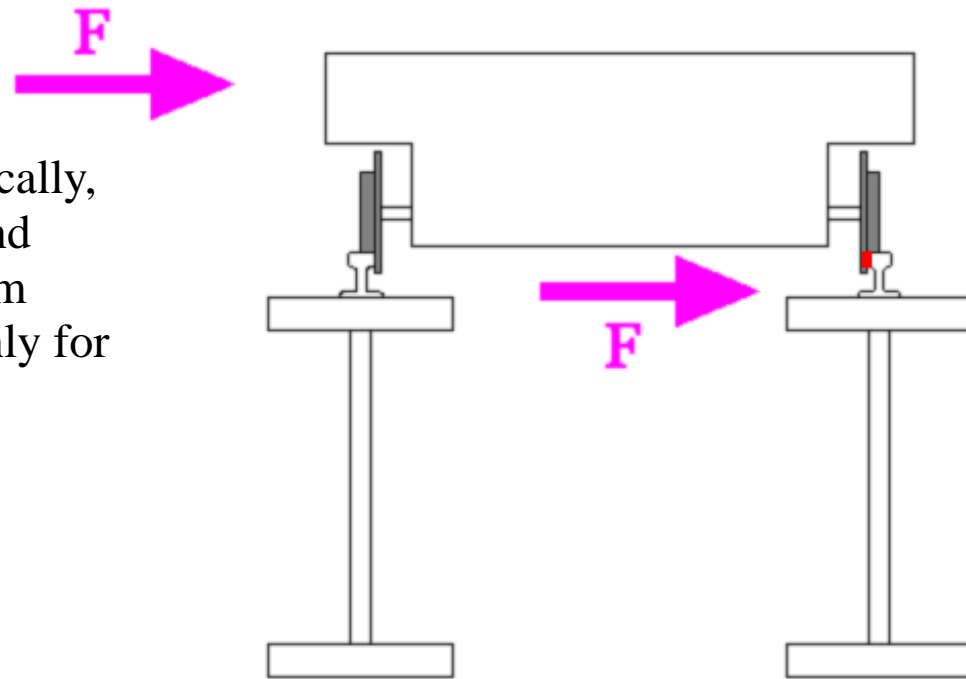


Photo: Author

Two sides flange wheel - theoretically, horizontal contact wheels-rail and transport of horizontal loads from crane to runbeams is possible for wheels on both sides of crane.

Distinction between two types of wheels is important for part of horizontal actions ( $\rightarrow$  #t / 89)

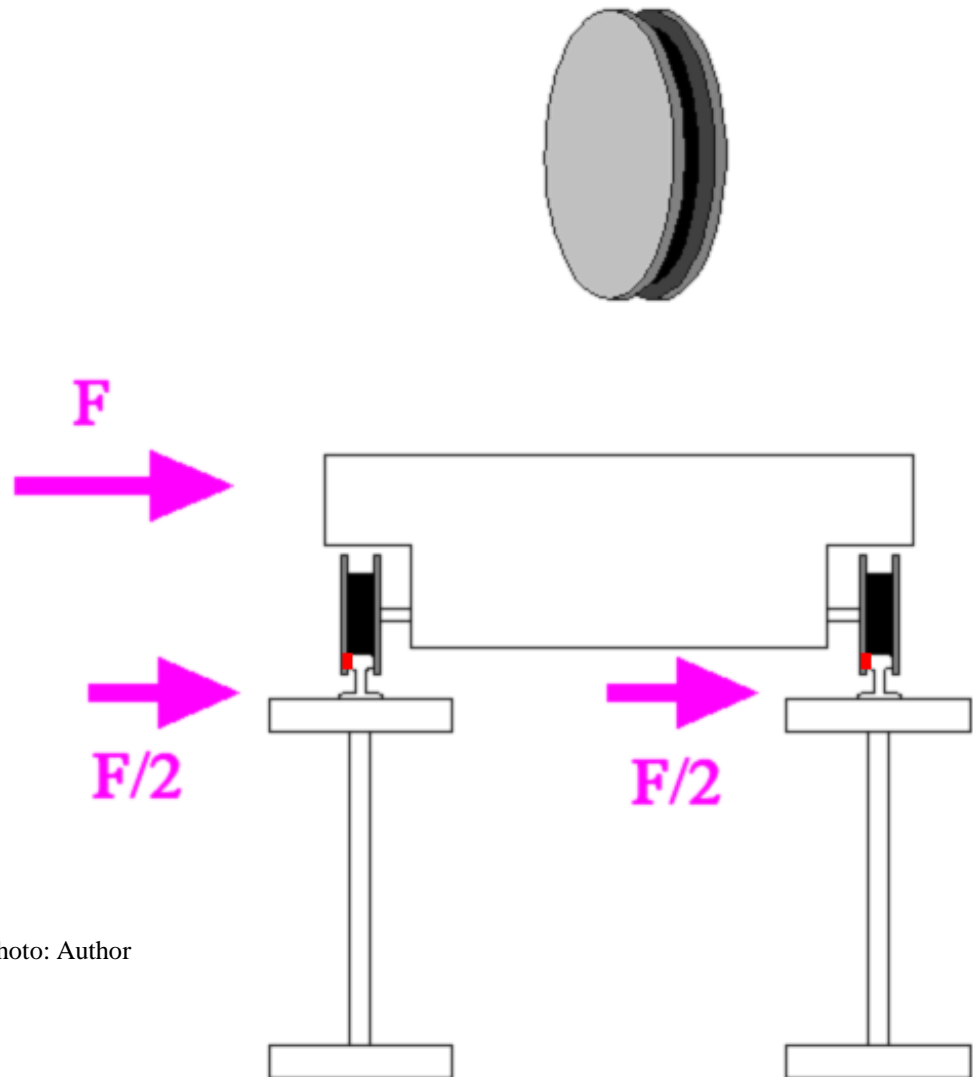
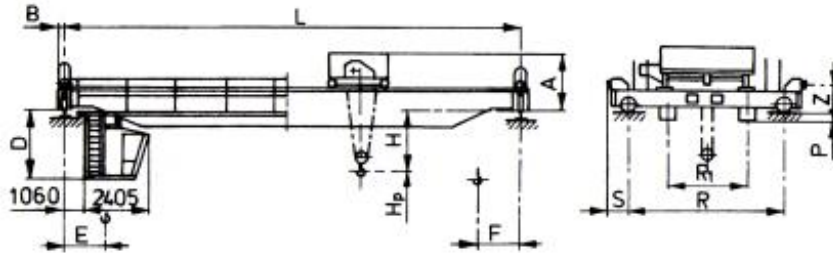


Photo: Author

## Loads and factors - values

$\phi_1$  ; self-weight of crane  $Q_c$



EN 1991-3 tab. 2.4

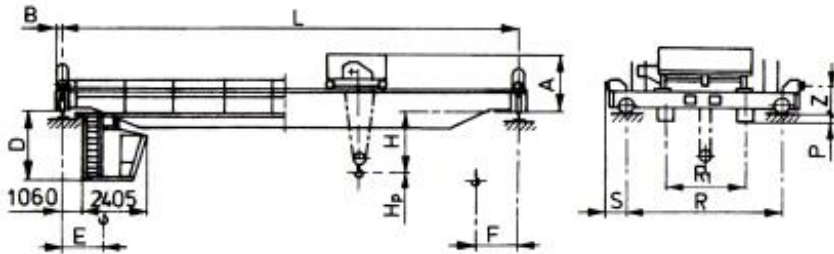
$\phi_1 = 0,9 , 1,1$

$Q_c$  - manufacturer's or investor's guidelines

Udźwig $Q$	Rozpię- tość $L$	Masa suw- nicy	Nacisk koła $N_{max}$	$H_{p\ max}$	$A_{max}$	$A_{min}$	B
kN	m	t	kN	m			
80	8-11	13,2	89	16,1	2215	1780	195
	11-14	14,5	93				
	14-17	16,0	96				
	17-20	17,2	99				
	20-23	20,2	108				
	23-26	22,0	114				
	26-29	25,8	124				

We should take 1,1 or 0,9 for calculations, in dependence of value of cross-sectional forces which we need.

Photo: W. Bogucki, M. Żybertowicz, Tablice do projektowania konstrukcji metalowych, Arkady, Warszawa 1996



$\varphi_2$  ; hoist load  $Q_h$



EN 1991-3 tab. 2.4

$$\varphi_2 = \varphi_{2,\min} + \beta_2 v_h$$

$v_h$  - steady hoisting speed  
[m/s]

$Q_h, v_h$  - manufacturer's  
or investor's guidelines

Udźwig $Q$	Rozpię- tość $L$	Masa suw- nicy	Nacisk koła $N_{max}$	$H_{p,max}$	$A_{max}$	$A_{min}$	B
kN	m	t	kN	m			
80	8-11	13,2	89	16,1	2215	1780	195
	11-14	14,5	93				
	14-17	16,0	96				
	17-20	17,2	99				
	20-23	20,2	108				
	23-26	22,0	114				
26-29	25,8	124					

Photo: W. Bogucki, M. Żybertowicz, Tablice do projektowania konstrukcji metalowych, Arkady, Warszawa 1996

EN 1991-3 tab. 2.5

Hoisting class of appliance	$\beta_2$	$\varphi_{2,\min}$
HC1	0,17	1,05
HC2	0,34	1,10
HC3	0,51	1,15
HC4	0,68	1,20

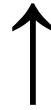
## Hoisting class of appliance → EN 1991-3 Appendix B

Item	Type of crane	Hoisting class	S-classes
1	Hand-operated cranes	HC 1	S0, S1
2	Assembly cranes	HC1, HC2	S0, S1
3	Powerhouse cranes	HC1	S1, S2
4	Storage cranes - with intermittennd operation	HC2	S4
5	Storage cranes, spreader bar cranes, scrap yard cranes -with continuous operation	HC3, HC4	S6 ,S7
6	Workshop cranes	HC2, HC3	S3,S4
7	Overhead travelling cranes, ram cranes - with grab or magnet operation	HC3, HC4	S6, S7
8	Casting cranes	HC2, HC3	S6, S7
9	Soaking pit cranes	HC3, HC4	S7, S8
10	Stripper cranes, charging cranes	HC4	S8, S9
11	Forging cranes	HC4	S6, S7
12	Transporter bridges, semi-portal cranes, portal cranes with trolley or slewing crane - with hook operation	HC2	S4, S5

...

$$\varphi_3 = 1 - \Delta m (1 + \beta_3) / m$$

$\varphi_3$  - release of payload



$\Delta m$  - part of full load  $m$ , which is released

EN 1991-3 tab. 2.4

Photo: eurotech-opole.pl

Photo: hak.com.pl

Photo: i01.i.aliimg.com



Release after put load on the ground

Slow release

Sudden release

$$\varphi_3 = 0,0$$

$$\beta_3 = 0,5$$

$$\beta_3 = 1,0$$

$\varphi_4$  - dynamic effects induced when the crane is travelling;



EN 1991-3 tab. 2.4

$$\varphi_4 = 1$$

provided that the tolerances for rail tracks as specified in EN 1993-6 are observed

otherwise

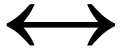
→ EN 13001-2

Parameter  $\eta$  - proportion of the hoist load that remains when payload is removed, but is not included in the self-weight of the crane

No information in Eurocode about value, manufacturer's or investor's guidelines only.

$\varphi_5$  - dynamic effects caused by drive forces

$H_{L,i}$  ;  $H_{T,i}$  - acceleration of crane bridge



The effect of acceleration and deceleration crane

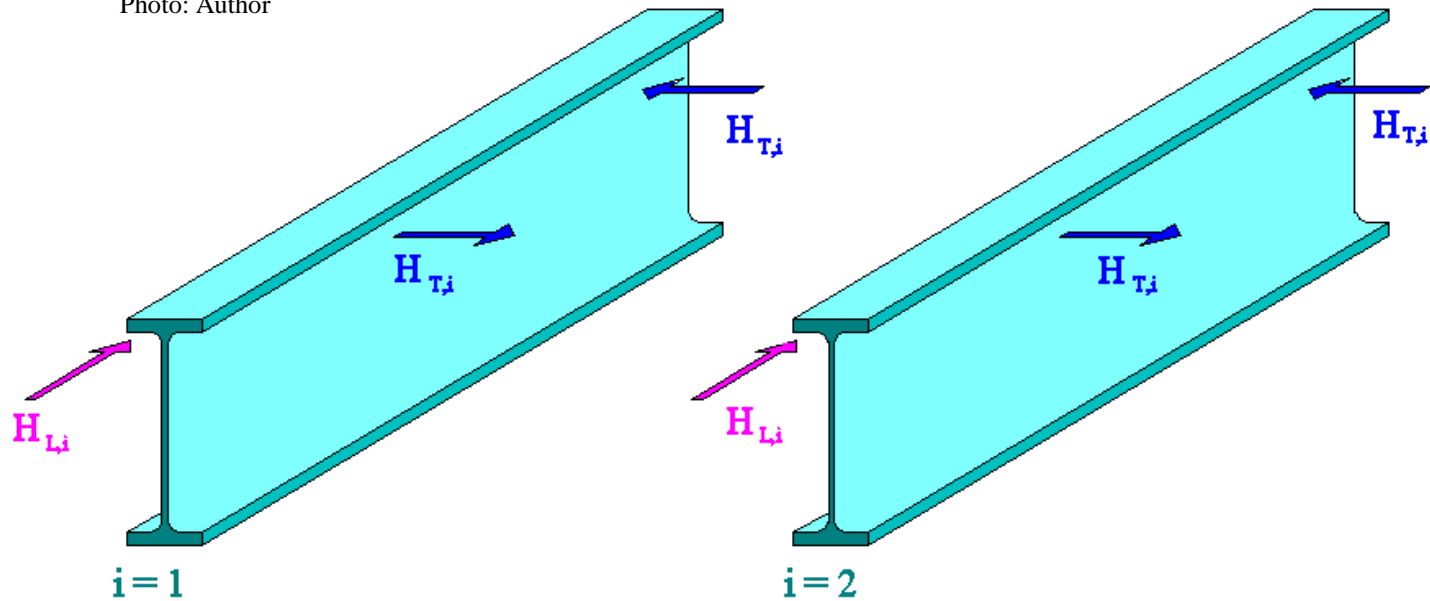
$\varphi_5$  - manufacturer's or investor's guidelines

or

EN 1991-3 tab. 2.6

Specific use	Values of the dynamic factor
For centrifugal forces	$\varphi_5 = 1,0$
For systems where forces change smoothly	$1,0 \leq \varphi_5 \leq 1,5$
For cranes where sudden changes occurs	$1,5 \leq \varphi_5 \leq 2,0$
For drivers with considerable backlash	$\varphi_5 = 3,0$

Photo: Author



EN 1991-3 (2.2), (2.3), (2.4)

$$H_{L,i} = \varphi_5 K / n_T$$

$$H_{T,i} = \varphi_5 \xi_j M / a$$

$$i, j = 1, 2 \quad ; \quad i \neq j$$

$n_T$  - number of runway beams

$K$  - drive force  $\rightarrow$  #t / 37

$M$  - torsional moment  $\rightarrow$  #t / 38

$\xi_j$  - proportion factor  $\rightarrow$  #t / 38

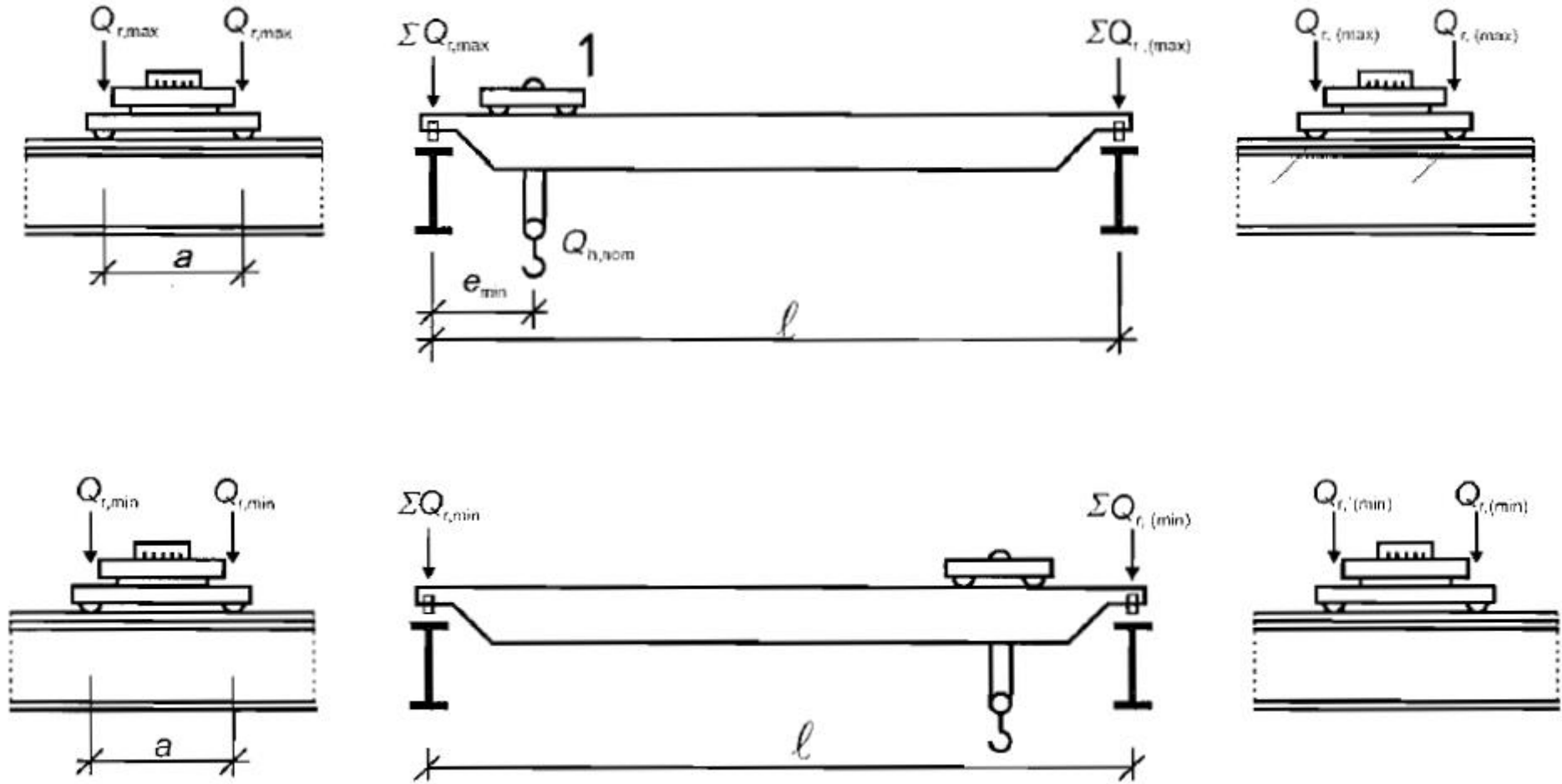
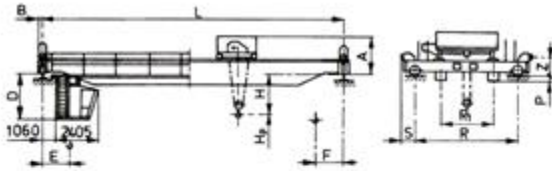


Photo: EN 1991-3 fig. 2.1

There are very important names of indexes:

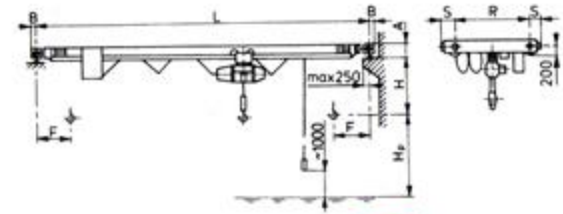
		Crab with hoist load next to		Value of loads	
		left beam	right beam		
Loads applied to	left beam	r, max	r, min	max	min
	right beam	r, (max)	r, (min)	min	max

Values of the loads are presented in tables:



Udźwig $Q$ kN	Rozpiętość $L$ m	Masa suwnicy $t$	Nacisk koła $N_{max}$ kN	$H_{p,max}$ m	$A_{max}$	$A_{min}$	B
80	8-11	13,2	89	16,1	2215	1780	195
	11-14	14,5	93				
	14-17	16,0	96				
	17-20	17,2	99				
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	29-32	27,3	129				
	32-35	30,3	136				
8-11	14,4	93					

W. Bogucki, M. Żybertowicz, Tablice  
projektowania konstrukcji metalowych, A  
Warszawa 1996, pp. 518-519



Udźwig $Q$ kN	Rozpiętość $L$ m	Masa $t$	Nacisk koła kN	R mm	S	
20	4-7	1,68	13,8	1600	286	
	7-10	1,90	14,8			
	10-12	2,43	16,5			2000
	12-13		17,4		2500	
	13-16	2,71	17,4		2500	326
	16-19	3,51	19,7		3000	
	19-21	4,85	23,3		3500	378
	21-22		24,5		4000	
	22-25	5,27	24,5		4000	286
	4-7	1,74	19,0		.....	

Wheel load (nacisk koła): these value can be treated as

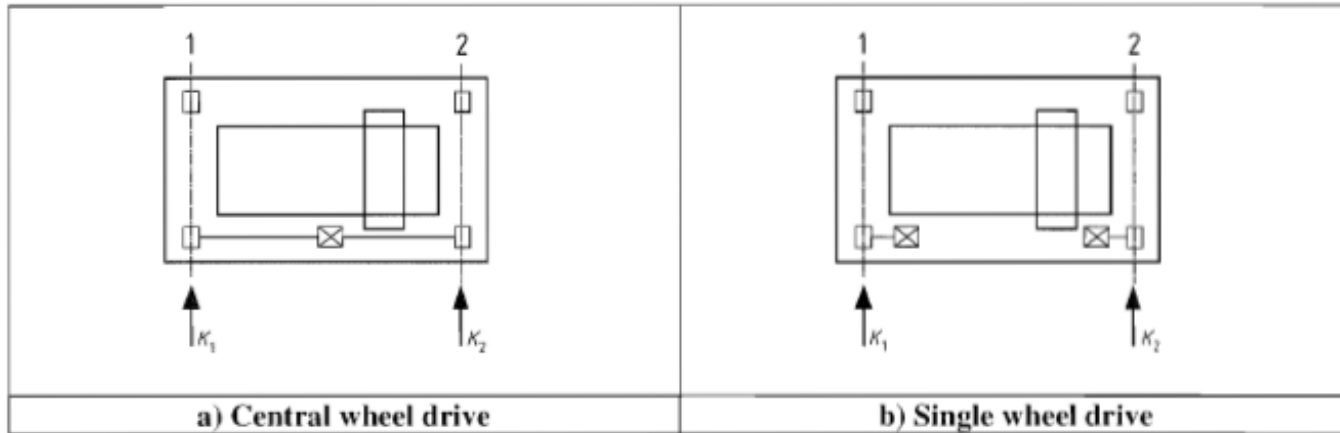
$$Q_{r, \max} \approx Q_{r, (\min)}$$

Reactions on the opposite pair of wheels:

$$2 Q_{r, (\max)} \approx 2 Q_{r, \min} \approx Q + g t - 2 (\text{wheel load})$$

$$K = K_1 + K_2 = \mu \Sigma Q_{r, \min}^*$$

EN 1991-3 (2.5)



	Central wheel drive	Single wheel drive
$\Sigma Q_{r, \min}^*$	$Q_{r, \min} + Q_{r, (\min)}$	$m_w Q_{r, \min}$

Photo: EN 1991-3 fig. 2.7

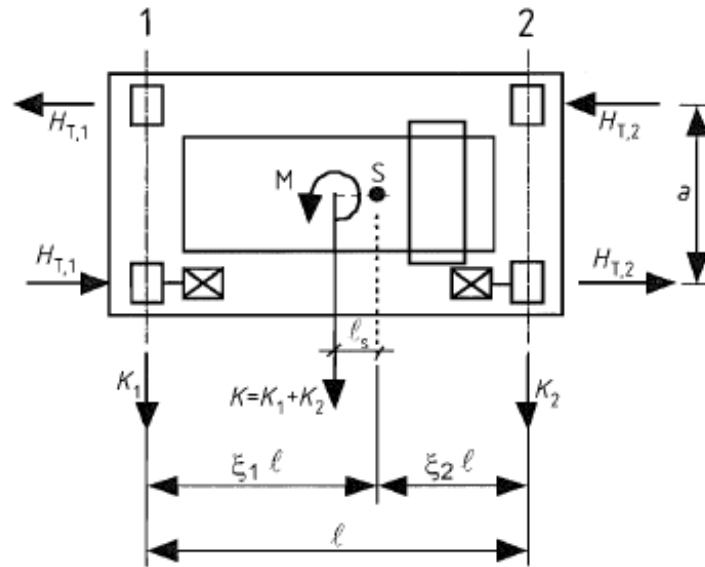
$m_w$  - number of single wheels drives

Friction factor:

steel-steel:  $\mu = 0,2$

steel-rubber (wheels with tyres):  $\mu = 0,5$

Photo: EN 1991-3 fig. 2.6



$$M = K l_s$$

$$l_s = l (\xi_1 - 0,5)$$

EN 1991-3 (2.4)

$$\xi_1 = \Sigma Q_{r, \max} / \Sigma Q_r$$

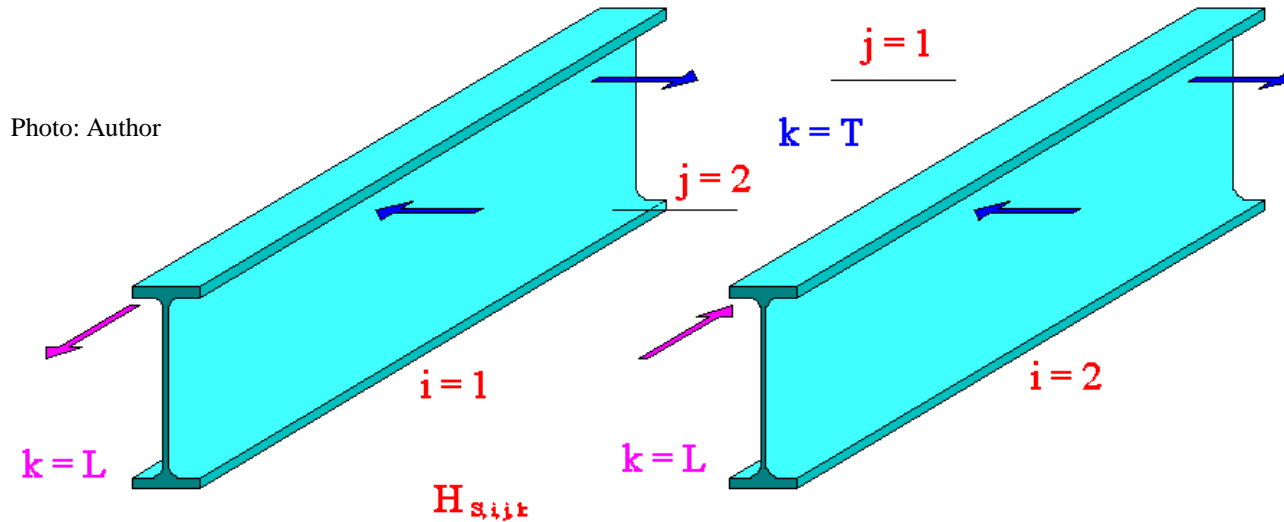
$$\xi_2 = 1 - \xi_1$$

$$\Sigma Q_r = \Sigma Q_{r, \max} + \Sigma Q_{r, (\max)}$$

# $H_{S,i,j,k}$ - skewing of crane bridge



The effect of the uneven application of forces drive to the wheels on both side of crane



EN 1991-3 (2.6), (2.7), (2.8), (2.9), (2.10)

$$S = \lambda_{S,j} f \Sigma Q_r$$

$$H_{S,i,j,k} = \lambda_{S,i,j,k} f \Sigma Q_r$$

f - "non-positive" factor  $\rightarrow$  #t / 42

$\lambda_S$  - force factors  $\rightarrow$  #t / 43

## Additional rules for $H_{S,i,j,k}$

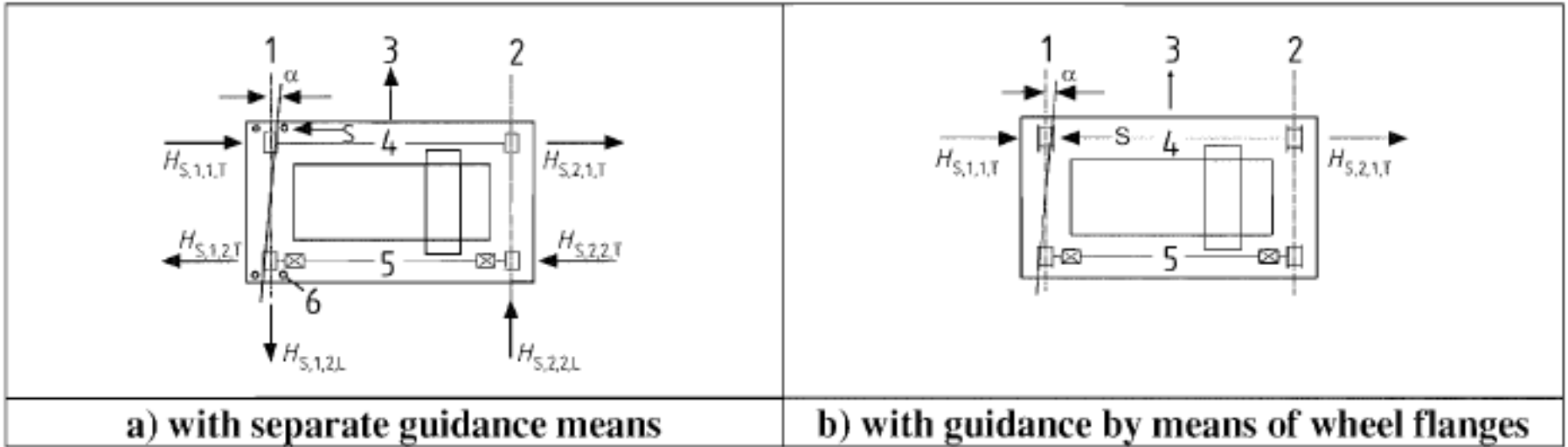


Photo: voith.at

Photo: EN 1991-3 fig. 2.4

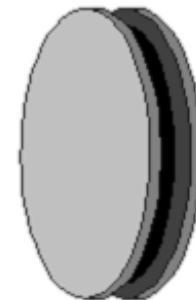
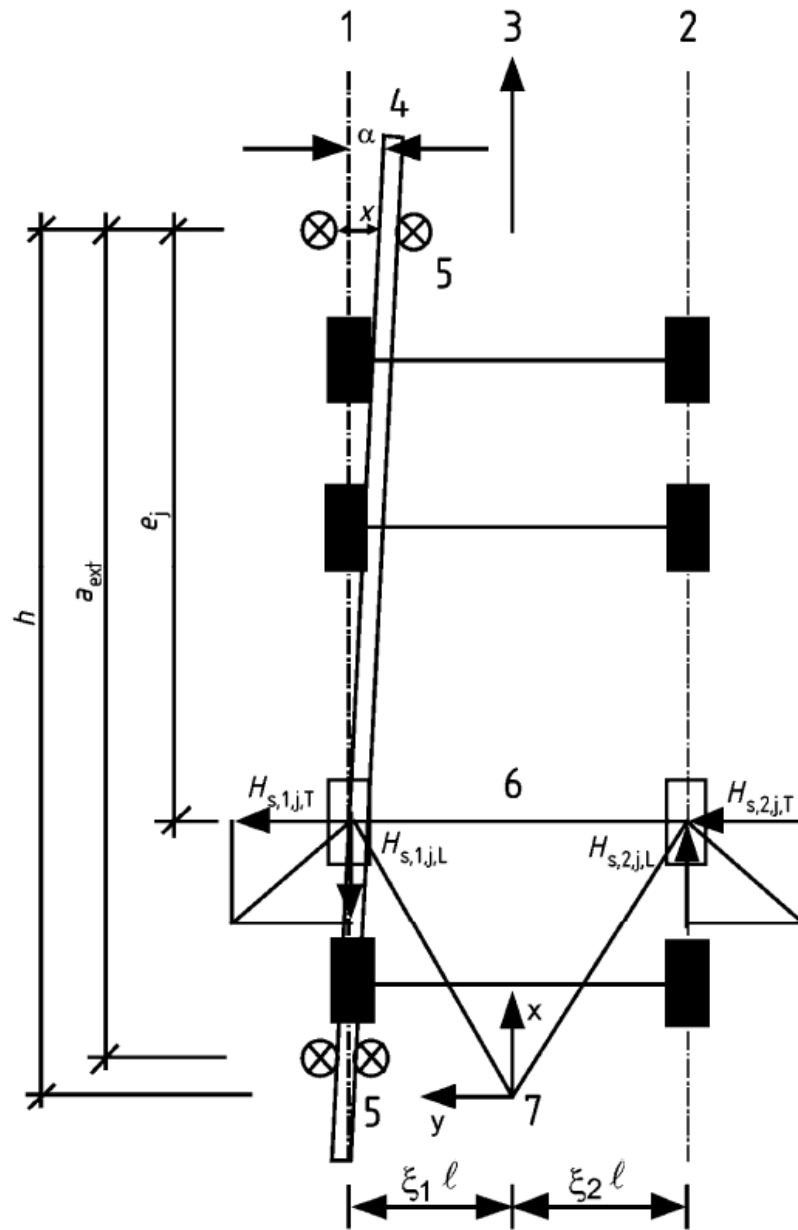


Photo: Author

Photo: EN 1991-3 fig. 2.8



$$f = \min \{ 0,3 \ ; \ 0,3[1 - \exp (-250\alpha) ] \}$$

$$\alpha = \min (\alpha_F + \alpha_V + \alpha_0 \ ; \ 0,015 \text{ rad})$$

EN 1991-3 (2.11)

Angles $\alpha$	Minimum values of
$\alpha_F = 0,75 x / a_{\text{ext}}$	$0,75 x \geq 5 \text{ mm}$ for guide rollers
	$0,75 x \geq 10 \text{ mm}$ for wheel flanges
$\alpha_V = y / a_{\text{ext}}$	$y \geq 0,03b$ [mm] for guide rollers
	$y \geq 0,1b$ [mm] for wheel flanges
$\alpha_0$	0,001 [rad]
<p><math>a_{\text{ext}}</math> – spacing of the outer guidance means or flanged wheels on the guiding rail;  <math>b</math> – width of the rail head;  <math>x</math> – track clearance between the rail and the guidance means (lateral slip);  <math>y</math> – wear of the rail and the guidance means;  <math>\alpha_0</math> – tolerance on wheel and rail directions;</p>	

EN 1991-3 tab. 2.7

System	$\lambda_{S,j}$	$\lambda_{S,1,j,L}$	$\lambda_{S,1,j,T}$	$\lambda_{S,2,j,L}$	$\lambda_{S,2,j,T}$
CFF	$S_{1F}$	$\xi_1 \xi_2 l / H$	$\xi_2 S_{1F}$	$\xi_1 \xi_2 l / H$	$\xi_1 S_{1F}$
IFF		0	$\xi_2 S_{1F}$	0	$\xi_1 S_{1F}$
CFM	$\xi_2 S_{1F}$	$\xi_1 \xi_2 l / H$	$\xi_2 S_{1F}$	$\xi_1 \xi_2 l / H$	0
IFM		0	$\xi_2 S_{1F}$	0	0

$n$  – number of wheel pair;

$\xi_1 l$  – distance of the instantaneous centre of rotation from rail 1;

$\xi_2 l$  – distance of the instantaneous centre of rotation from rail 2;

$l$  – span of the appliance;

$e_j$  – distance of the wheel pair  $j$  from the relevant guidance means;

$h$  – distance between the instantaneous centre of rotation and the relevant guidance means;

$$H = n h$$

$$S_F = (\sum e_j)$$





$$S_{1F} = 1 - S_F / H$$

$$\xi_1, \xi_2 \rightarrow \#t / 38$$

$$h, e_j \rightarrow \#t / 41$$

$$\text{CCF, IFF, CFM, IFM} \rightarrow \#t / 44$$

EN 1991-3 tab. 2.9

Fixing of wheels according to lateral movements	Combination of wheel pairs		h
	Coupled (C)	Independent (I)	
Fixed / Fixed (FF)			$[m \xi_1 \xi_2 l^2 + \Sigma (e_j)^2] / \Sigma e_j$
Fixed / Movable (FM)			$[m \xi_1 l^2 + \Sigma (e_j)^2] / \Sigma e_j$

h – distance between the instantaneous centre of rotation and the relevant guidance means;

m – number of pairs of coupled wheels (m = 0 for independent wheel pairs);

$\xi_1 l$  – distance of the instantaneous centre of rotation from rail 1;

$\xi_2 l$  – distance of the instantaneous centre of rotation from rail 2;

l – span of the appliance;

$e_j$  – distance of the wheel pair j from the relevant guidance means;

EN 1991-3 tab. 2.8

Forces from acceleration of crane bridge

VS

Forces from skewing of crane bridge

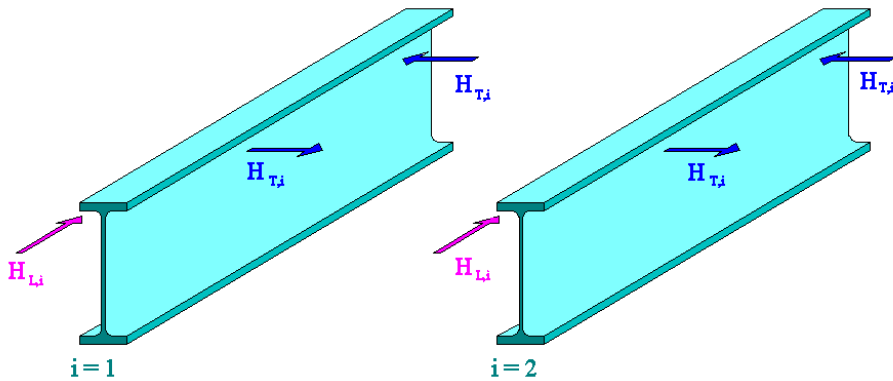
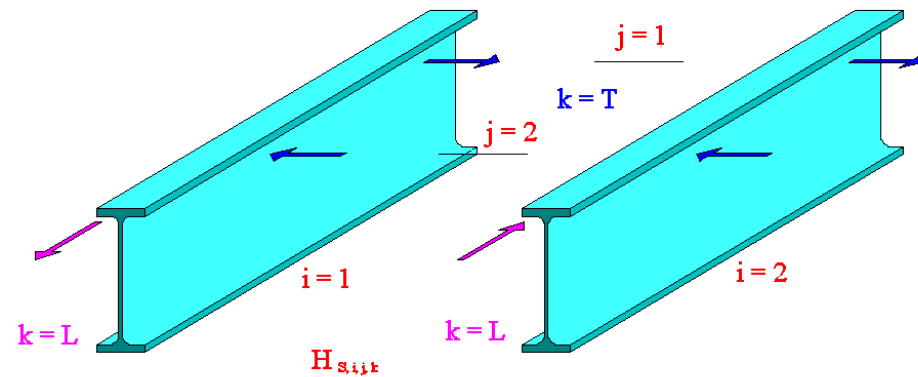


Photo: Author



Very similar complex of forces, but reasons of them are different.

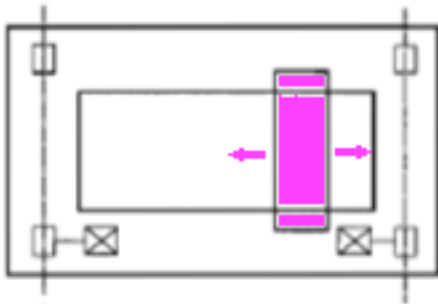
## Forces from acceleration of crane bridge

Reason: eccentricity between centre of gravity and drive axis.

Drive axis lies on half distance between both runbeam.

Location of momentary center of gravity depends on momentary location of crab of crane. Crab of crane can change its position during operating.

Eccentricity makes dynamic torsional moment  $M$  during changing velocity (acceleration / deceleration) of crane.



## Forces from skewing of crane bridge

Reason: uneven application of forces drive to the wheels on both side of crane. This is effect of imperfections of structure, wheels of crane and engine.

Uneven application of force makes difference between theoretical drive axis (parallel to runbeams) and real momentary driving direction.

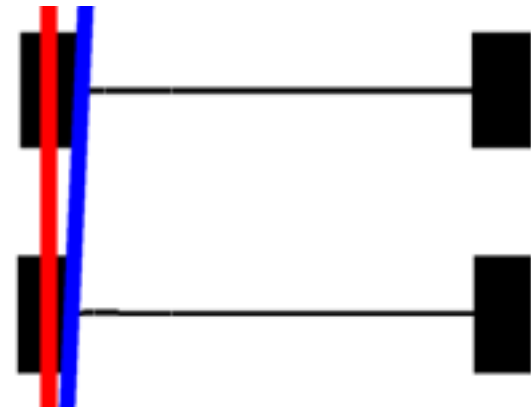


Photo: Author

$H_{T3}$  - acceleration or braking of crab or hoist block  $\longleftrightarrow$

Acceleration or braking of crab or hoist block can be covered by horizontal force  $H_{B,2}$  (buffer forces related to movements of crab), given in EN 1991-3 2.11.2  $\rightarrow$  #t / 48

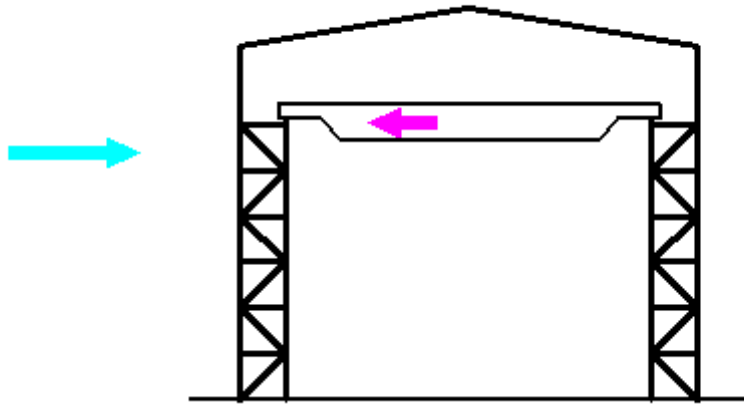
EN 1991-3 2.7.5

Buffer forces related to movements of crab  $H_{B,2}$   $\longleftrightarrow$

- Buffer forces related to movements of crab can be assumed as:  
0,1 (self-weight of crab + hoist load);
- In other case, this force should be determined as for the crane movement  $\rightarrow \#t / 58$ ;

EN 1991-3 2.11.2

A



Wind action

B

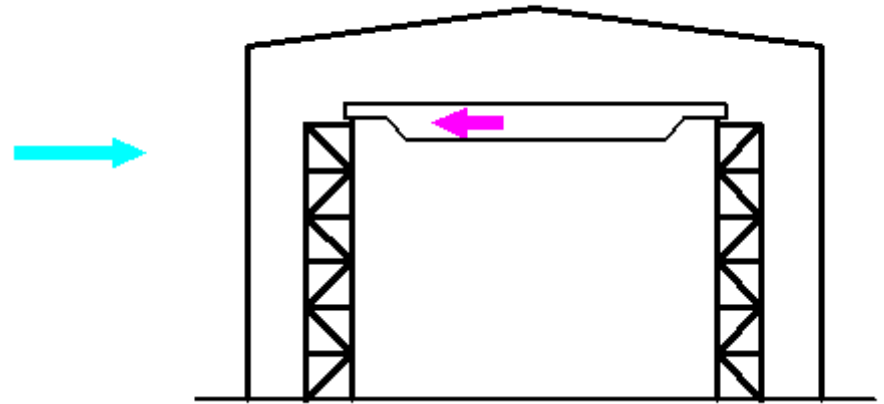
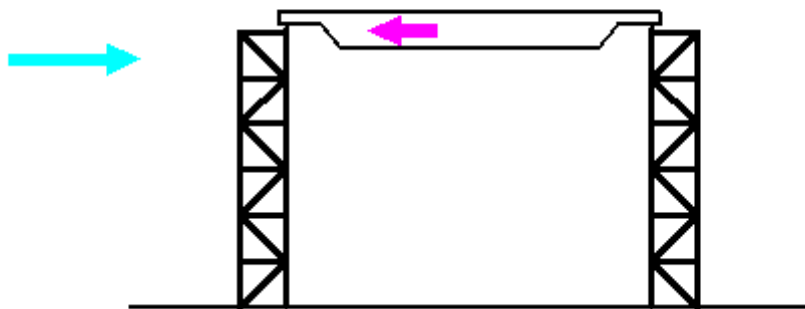


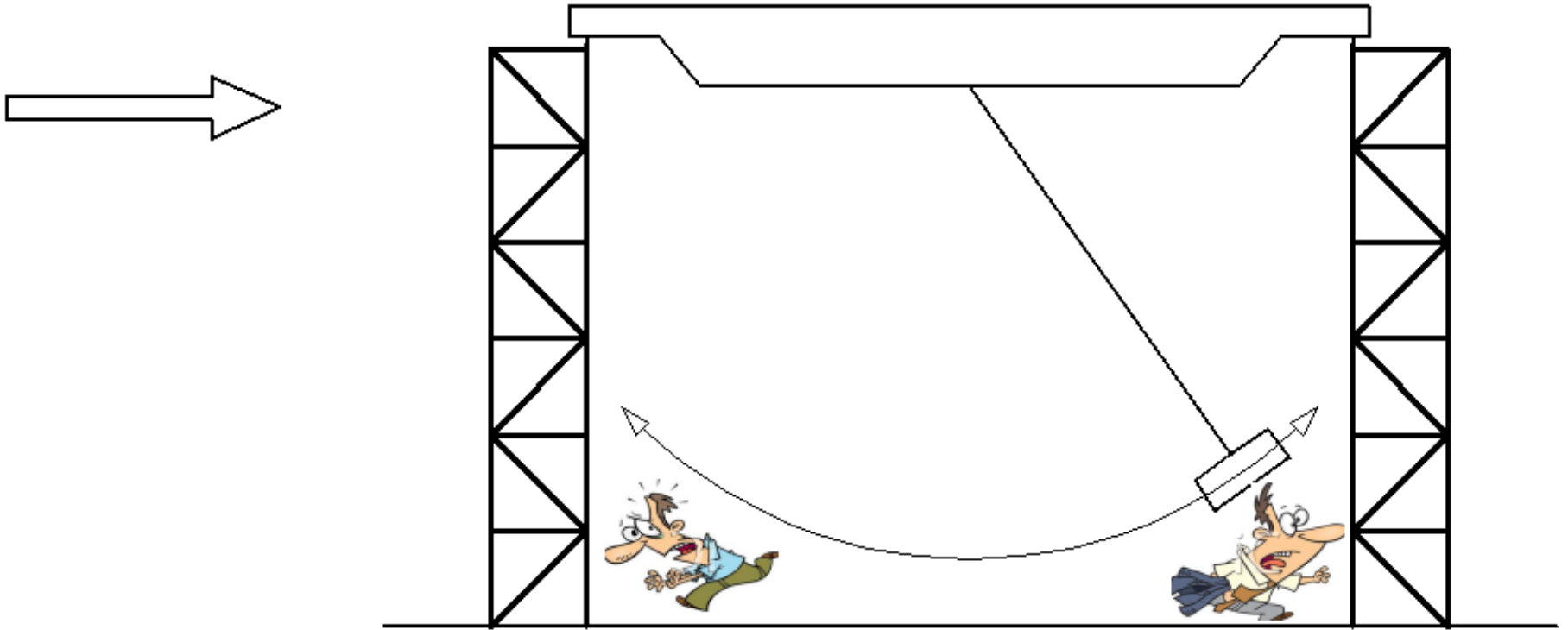
Photo: Author



C

There is big difference for wind action on these three types of structure. Wind must be analyzed in detail for case C.

Photo: Author



Strong wind can be dangerous for workers, structure, crane and payload.

We must analysed two cases:

medium wind when crane is working

strong wind when crane is stopped

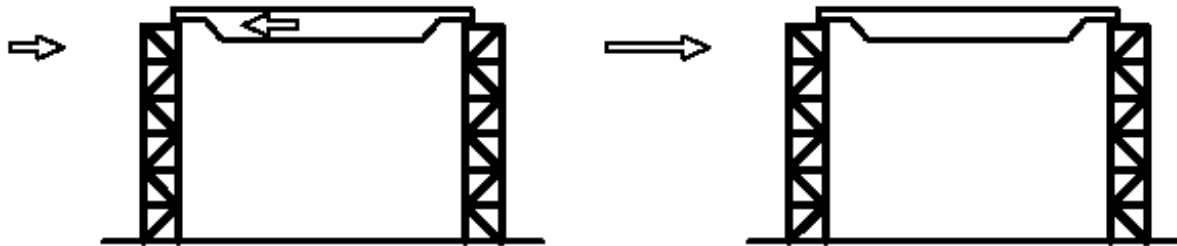


Photo: Author

Medium wind:

20 m /s

EN 1991-3 A.1 (6)

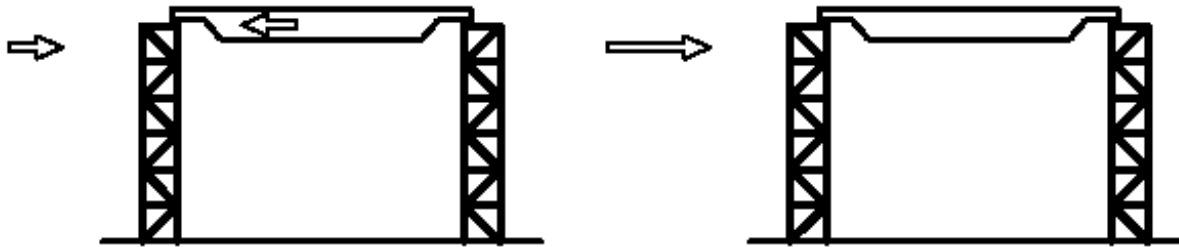
Strong wind - according to EN 1991-1-4:

	V [m/s]
1	22
2	26
3	22



Photo: EN 1991-1-4 fig. NB.1

Photo: Author



Types of loads, which are analysed:

$F (V = 20 \text{ m/s})$	$F (V = 22 - 26 \text{ m/s})$
$\varphi_1 Q_c$	$Q_c$
$\varphi_2 Q_h$	$P$
$\varphi_3 Q_h$	...
$\varphi_4 Q_c$	
$H_{L,i} ; H_{T,i}$	
$H_{S,i,j,k}$	
$\varphi_6 Q_T$	
$H_B$	
$H_{TA}$	
$P$	
...	

$P$  - walkways, stairs, platforms, guard rails  
... - other loads (thermal action, during execution, accidental...)

Generally, there are two directions of wind actions:

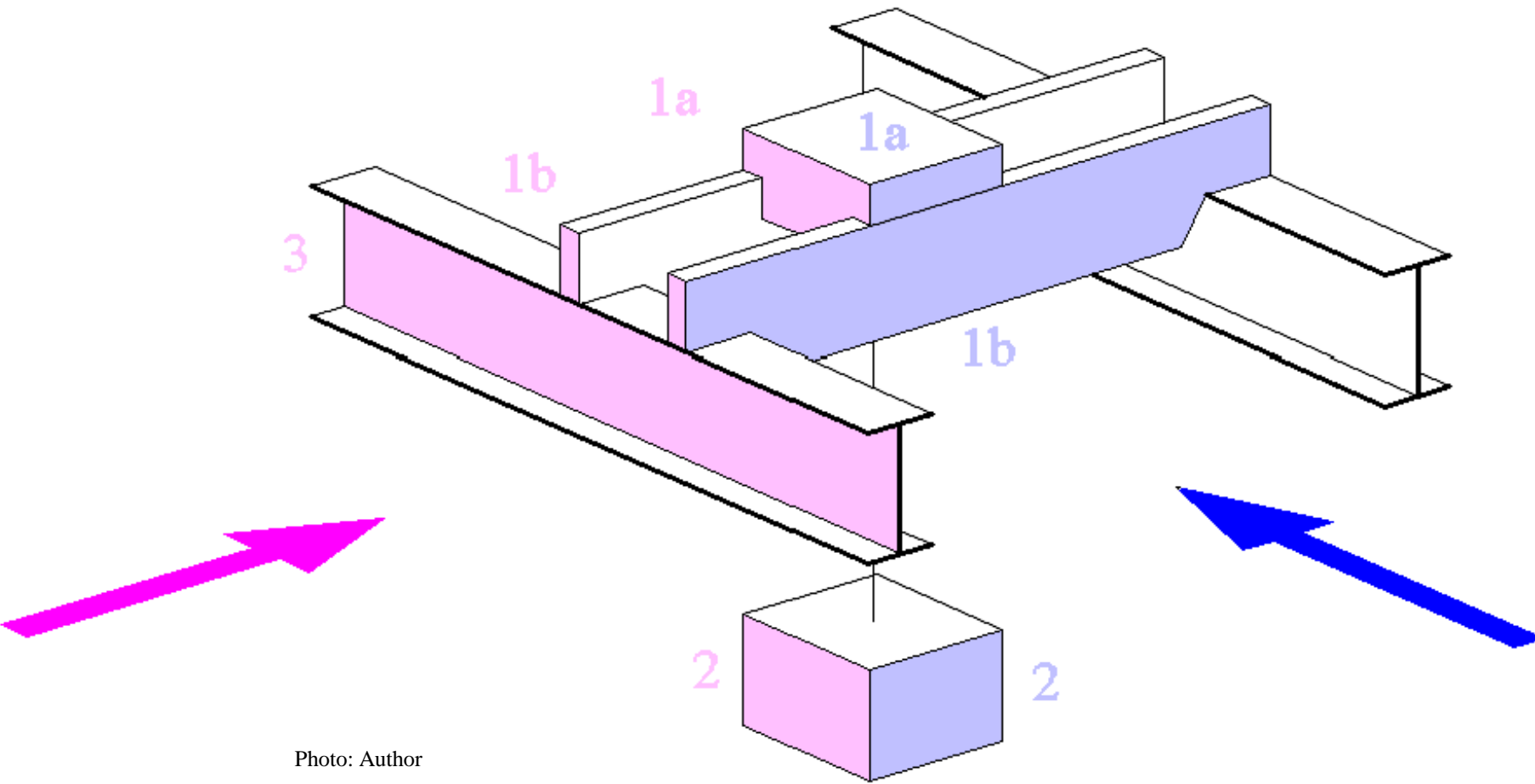
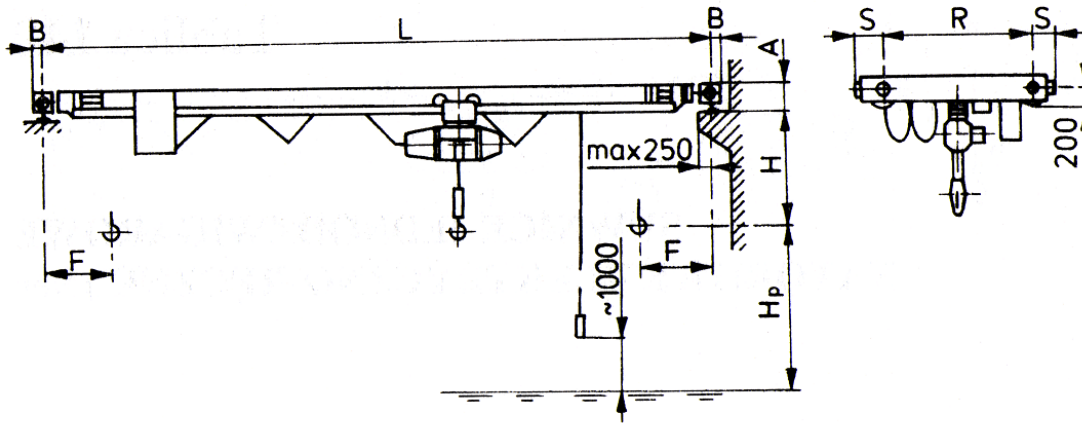


Photo: Author

## Effective area of different part of crane:



$$1a \approx 0$$

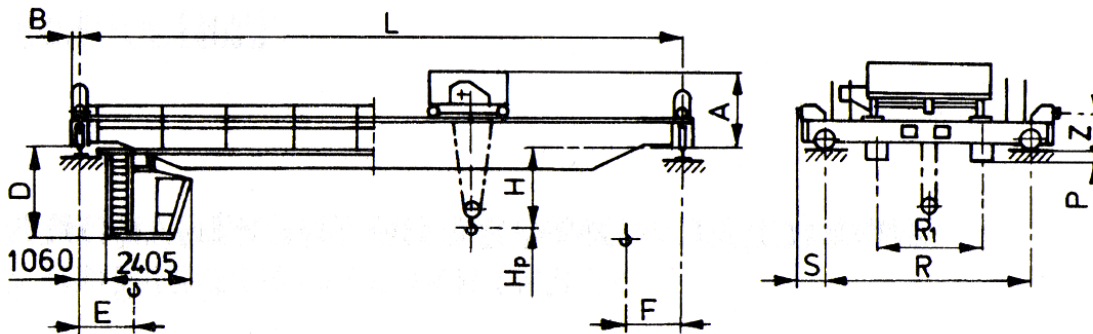
$$1b \approx LA$$

$$1a \approx RA$$

$$1b \approx 0$$

Photo: W. Bogucki, M. Żybertowicz, Tablice do projektowania konstrukcji metalowych, Arkady, Warszawa 1996

$3 = \text{length of runbeam} \cdot \text{high of runbeam}$



Area of payload (2):

$A_{\text{ref},x}$  - manufacturer's or investor's guidelines

or

PN-M 06514

$$A_{\text{ref},x} [\text{m}^2] = Q_h [\text{t}] \quad Q_h \leq 12,5 \text{ t}$$

$$A_{\text{ref},x} [\text{m}^2] = 3,5 \sqrt{Q_h [\text{t}]} \quad Q_h > 12,5 \text{ t}$$

$\varphi_6$  ; test load  $Q_T$  ↓

Static test load	Dynamic test load
$Q_T \geq 1,25 Q_h$	$Q_T \geq 1,10 Q_h$
$\varphi_6 = 1$	$\varphi_6 = 0,5 ( 1 + \varphi_2)$

EN 1991-3 (2.13), (2.14)

$\varphi_7$  ; buffer forces  $H_B$



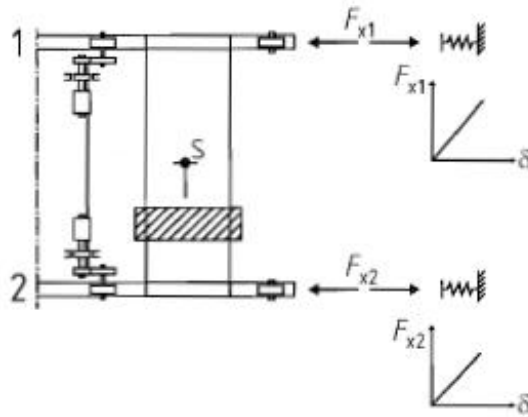
EN 1991-3 (2.15)

$$H_{B,1} = \varphi_7 v_1 \sqrt{m_c S_B}$$

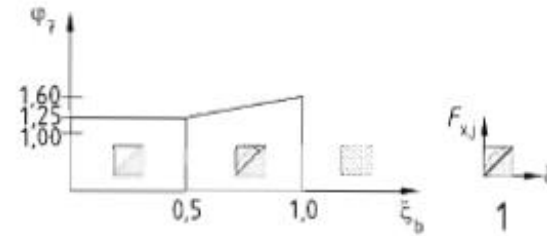
$$v_1 = 0,7 v_{\max}$$

Buffer characteristic	Values of dynamic factor $\varphi_7$
$0,0 \leq \xi_b \leq 0,5$	1,25
$0,5 \leq \xi_b \leq 1,0$	$1,25 + 0,7 (\xi_b - 0,5)$
$\xi_b$ may be approximately determined from fig. 2.9	

EN 1991-3 tab. 2.10



a) Buffer force



b) Buffer characteristic  $\xi_b = \frac{1}{F u} \int_0^u F du$

Buffer characteristic

$$\xi_b = \left\{ 1 / [F(u_{\max}) u_{\max}] \right\} \int_0^{u_{\max}} [F(u)] du$$

means

[1 / (energy for max deformation of buffers)] [energy dissipated by buffers during barking]

Function  $F(u)$  is characteristic of buffer, different for various types. It should be specified by manufacturer or investor.

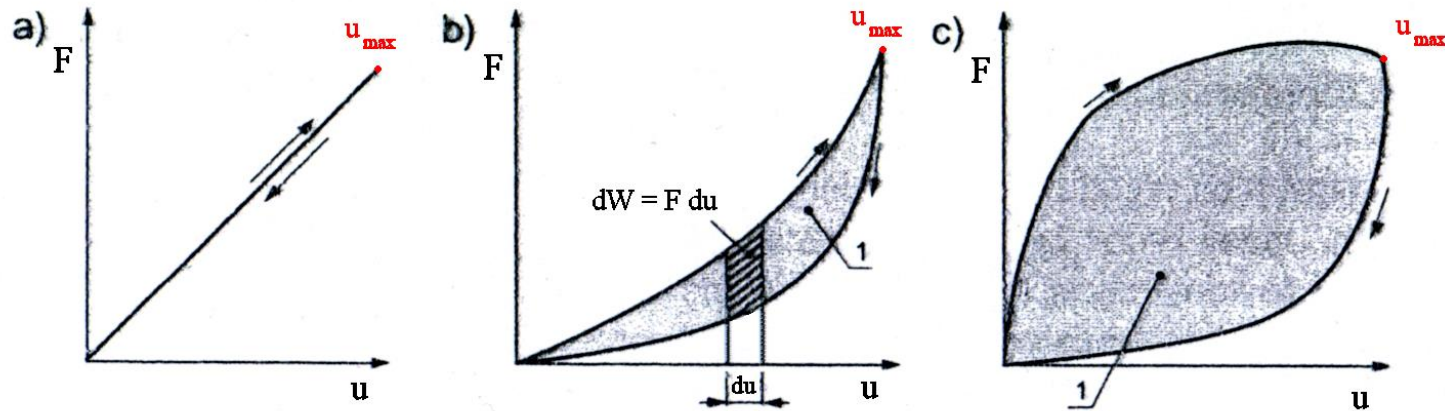


Photo: Hale o konstrukcji stalowej, poradnik projektanta, Kucharczuk W. Labocha S. , PWN 2012

- a) Steel spring buffer
- b) Hydraulic buffer
- c) Rubber buffer

1 - energy dissipated in one cycle

Energy dissipated in one cycle in case a:  $S_b u_{max}^2 / 2$

$$F = F (S_B , u)$$

$$\xi_b = \{ 1 / [F(u_{\max}) u_{\max}] \} \int_0^{u_{\max}} [F (u)] du$$

Example for steel spring buffer:

$$F = S_B u$$

$$F(u_{\max}) = S_B u_{\max}$$

$$\begin{aligned} \xi_b &= \{ 1 / [F(u_{\max}) u_{\max}] \} \int_0^{u_{\max}} [F (u)] du = [1 / (S_B u_{\max}^2)] \int_0^{u_{\max}} (S_B u) du = \\ &= [1 / (S_B u_{\max}^2)] S_B \int_0^{u_{\max}} u du = [1 / (S_B u_{\max}^2)] S_B u_{\max}^2 / 2 = \\ &= S_B u_{\max}^2 / (2 S_B u_{\max}^2) = 0,5 \end{aligned}$$

$$\xi_b = 0,5 \rightarrow \phi_7 = 1,25$$

$$H_{B,1} = 0,875 v_{\max} \sqrt{ ( m_c S_B )}$$

Tilting forces  $H_{TA}$



EN 1991-3 p. 2.11.3

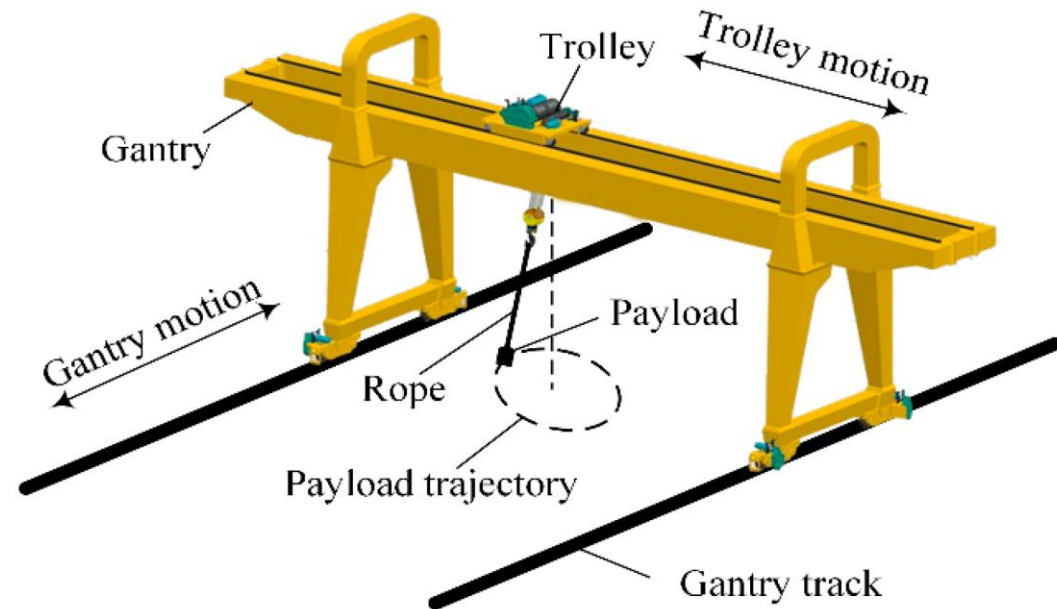


Photo: Research on Nonlinear Control Method of Underactuated Gantry Crane Based on Machine Vision Positioning, H. Shi, G. Li, X. Bai, J. Huang

- ◆ For crane with horizontally restrained of loads;
- ◆ In case of collision of load or lifting with an obstacle;
- ◆ No information in Eurocode about formulas or values of additional forces in this case;



Photo: manulift.com.pl

Tilting forces should be analysed first of all in case of rigid lifting.

Manufacturer should give information about such case of forces.



Photo: manulift.com.pl

## Monorail hoist block

Vertical forces:

- $\varphi_1$  ; self-weight  $Q_c$ ;
- $\varphi_2$  ; hoist load  $Q_h$ ;
- $\varphi_6$  ; test load  $Q_T$ ;

Forces and factors are calculated in the same way as for cranes.

Horizontal longitudinal force:

- 0,05 (self-weight + hoist load); no dynamic factors;



Photo: eurotech-opole.pl

EN 1991-3 p. 2.5

## Workers activity

Photo: megatem-ec.pl



- ◆ Vertical forces are applied to area  $0,3 \times 0,3 \text{ m}$ ;
- ◆ Where materials can be deposited,  $Q_k = 3,0 \text{ kN}$ ;
- ◆ If stairs, platforms and walkways are provided for normal access only,  $Q_k = 1,5 \text{ kN}$ ;
- ◆ Horizontal loads applied to guardrails,  $H_k = 0,3 \text{ kN}$ ;
- ◆ Each loads can be omitted, when structural memebers are subjected to crane actions;

EN 1991-3 p. 2.9

## Fatigue loads

$$\gamma_{Ff} \Delta\sigma_E / (\sigma_R / \gamma_{Mf}) \leq 1,0$$
$$\gamma_{Ff} \Delta\tau_E / (\tau_R / \gamma_{Mf}) \leq 1,0$$

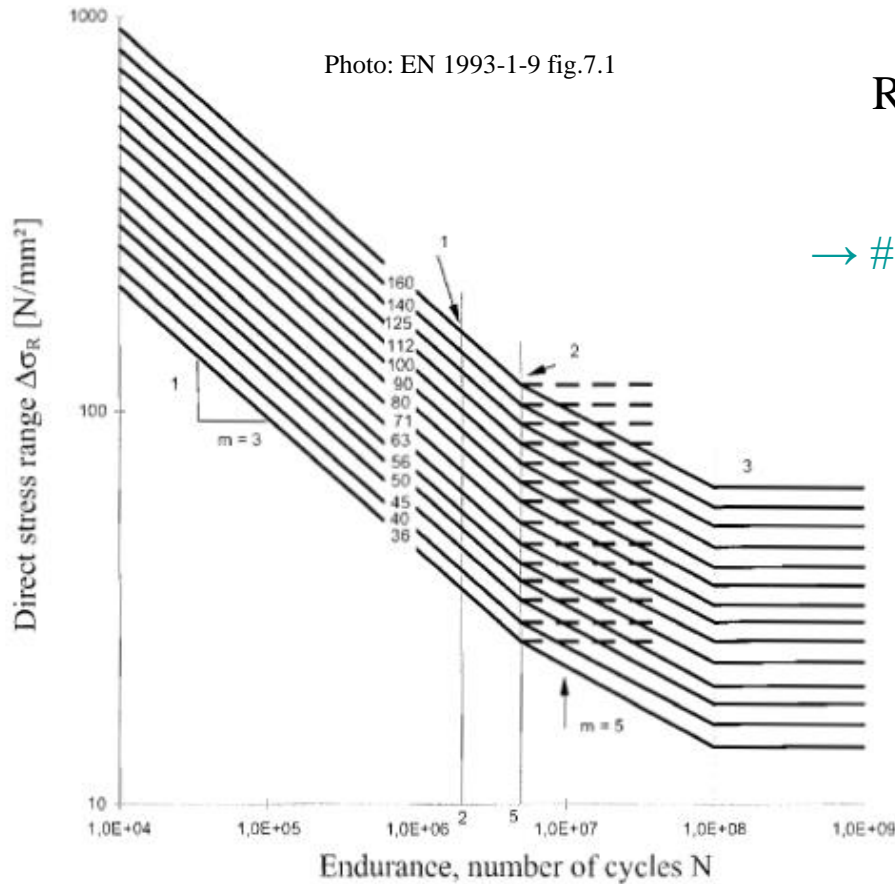
EN 1993-1-9 (8.2)

Checking of fatigue resistance will be presented on Lecture #4, at now only calculation of load is presented.

Photo: EN 1993-1-9 fig.7.1

Resistance depends on number of cycles  $N_R$

→ #1 / 75



EN 1991-3-9 7.1 (2)

- 1 Detail category  $\Delta\sigma_C$
- 2 Constant amplitude fatigue limit  $\Delta\sigma_D$
- 3 Cut-off limit  $\Delta\sigma_L$

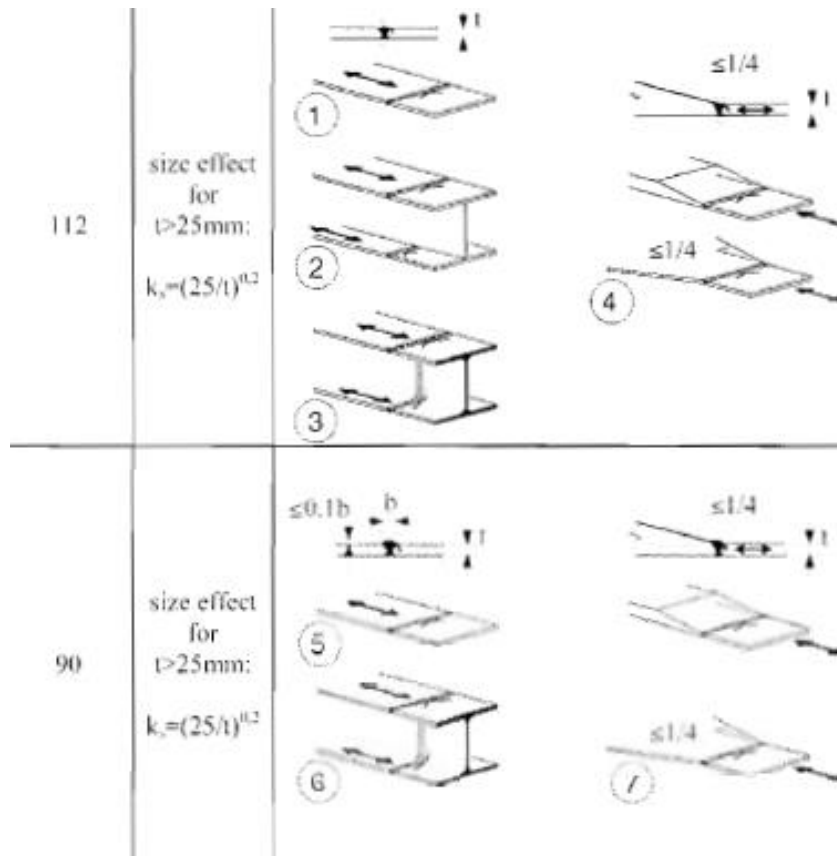
$$\Delta\sigma_R = \Delta\sigma_C \sqrt[m]{2 \cdot 10^6 / N_R}$$

$$\Delta\tau_R = \Delta\tau_C \sqrt[m]{2 \cdot 10^6 / N_R}$$

$m = 3$  for  $N_R = 10\,000 - 5\,000\,000$   
 $m = 5$  for  $N_R = 5\,000\,000 - 100\,000\,000$   
 $\Delta\sigma_R, \Delta\tau_R$  are constant for  $N_R > 100\,000\,000$

$\Delta\sigma_C$ ,  $\Delta\tau_C$  basic values of resistance;  
depends on different types of notches

EN 1993-1-9 tab. 8.1 - 8.10 for bar members



$$\Delta\sigma_E = \Delta\sigma_E (Q_e)$$

$$\Delta\tau_E = \Delta\tau_E (Q_e)$$

$$Q_e = Q_{\max,i} \varphi_{\text{fat}} \lambda_i$$

$$Q_{\max,i} \rightarrow \#t / 34 - 36$$

$$\varphi_{\text{fat}} = \max ( \varphi_{\text{fat},1} \ ; \ \varphi_{\text{fat},2} )$$

$$\varphi_{\text{fat},1} = (1 + \varphi_1) / 2$$

$$\varphi_{\text{fat},2} = (1 + \varphi_2) / 2$$

$$\lambda_i \rightarrow \#t / 70$$

EN 1991-3 (2.16), (2.19)

$\lambda_i$  damage equivalent factor

EN 1991-3 2.12.1

	Simplified approach EN 1991-3	Semi-accurate approach EN 1991-3, EN 13001-1	Accurate approach EN 1991-3, EN 13001-1
kQ	-	EN 13001-1	
S <sub>X</sub>	EN 1991-3 app. B	EN 1991-3 tab. 2.11	-
$\lambda_i$	EN 1991-3 tab. 2.12		EN 1991-3 (2.17), (2.18)

kQ - load spectrum factor

S<sub>X</sub> - crane class

	Simplified approach EN 1991-3	Semi-accurate approach EN 1991-3, EN 13001-1	Accurate approach EN 1991-3, EN 13001-1
$k_Q$	#t / 72	#t / 73	
$S_X$	#t / 74	#t / 75	#t / 76
$\lambda_i$	#t / 77		#t / 78

$k_Q$ , load spectrum factor - simplified approach

Not exists

# kQ - load spectrum factor - semi-accurate and accurate approach

EN 13001-1

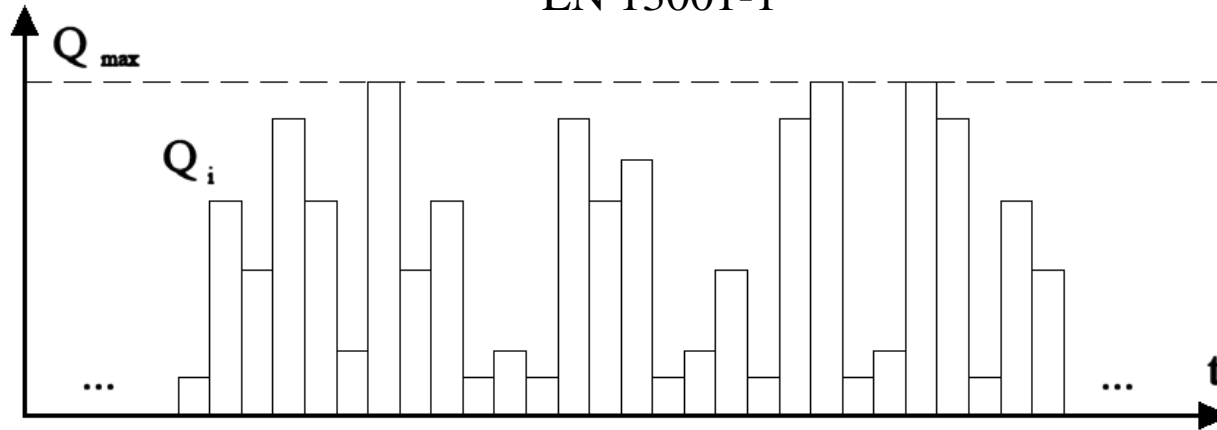


Photo: Author

$C_i$  number of working cycles with load  $Q_i$

Total number of working cycles  $C = \sum C_i$

$$kQ = \frac{\sum (C_i Q_i^m)}{(C Q_{\max}^m)}$$

$$m = 3 \text{ for } \Delta\sigma_E \quad m = 5 \text{ for } \Delta\tau_E$$

Generally, exact data about  $C_i$  and  $Q_i$  are available after end of working life of structure.  
There are only suppositions during designing of structure.

## $S_x$ , crane class - simplified approach

### EN 1991-3 Appendix B

Item	Type of crane	Holisting class	S-classes
1	Hand-operated cranes	HC 1	S0, S1
2	Assembly cranes	HC1, HC2	S0, S1
3	Powerhouse cranes	HC1	S1, S2
4	Storage cranes - with intermited operation	HC2	S4
5	Storage cranes, spreader bar cranes, scrap yard cranes -with continuous operation	HC3, HC4	S6, S7
6	Workshop cranes	HC2, HC3	S3, S4
7	Overhead travelling cranes, ram cranes - with grab or magnet operation	HC3, HC4	S6, S7
8	Casting cranes	HC2, HC3	S6, S7
9	Soaking pit cranes	HC3, HC4	S7, S8
10	Stripper cranes, charging cranes	HC4	S8, S9
11	Forging cranes	HC4	S6, S7
12	Transporter bridges, semi-portal cranes, portal cranes with trolley or slewing crane - with hook operation	HC2	S4, S5

$S_x$ , crane class - semi-accurate approach

Function of  $kQ$  and  $C$  ( $\rightarrow$  #t / 73)

EN 1991-3 table 2.11

Class of load spectrum		$Q_0$	$Q_1$	$Q_2$	$Q_3$	$Q_4$	$Q_5$
		$\frac{kQ}{13} \leq 0,03$	$0,0313 < \frac{kQ}{0,0625} \leq$	$0,0625 < \frac{kQ}{0,125} \leq$	$0,125 < \frac{kQ}{0,25} \leq$	$0,25 < \frac{kQ}{0,5} \leq$	$0,5 < \frac{kQ}{1,0} \leq$
class of total number of cycles							
$U_0$	$C \leq 1,6 \cdot 10^4$	$S_0$	$S_0$	$S_0$	$S_0$	$S_0$	$S_0$
$U_1$	$1,6 \cdot 10^4 < C \leq 3,15 \cdot 10^4$	$S_0$	$S_0$	$S_0$	$S_0$	$S_0$	$S_1$
$U_2$	$3,15 \cdot 10^4 < C \leq 6,30 \cdot 10^4$	$S_0$	$S_0$	$S_0$	$S_0$	$S_1$	$S_2$
$U_3$	$6,30 \cdot 10^4 < C \leq 1,25 \cdot 10^5$	$S_0$	$S_0$	$S_0$	$S_1$	$S_2$	$S_3$
$U_4$	$1,25 \cdot 10^5 < C \leq 2,50 \cdot 10^5$	$S_0$	$S_0$	$S_1$	$S_2$	$S_3$	$S_4$
$U_5$	$2,50 \cdot 10^5 < C < 5,00 \cdot 10^5$	$S_0$	$S_1$	$S_2$	$S_3$	$S_4$	$S_5$

$S_X$ , crane class - accurate approach

Not exists

Value of  $\lambda_i$  - simplified approach and semi-accurate approach

Function of  $S_x$  ( $\rightarrow$  #t / 74 for s.a. or 75 for s-a. a.)

EN 1991-3 table 2.12

Classes S	$S_0$	$S_1$	$S_2$	$S_3$	$S_4$	$S_5$	$S_6$	$S_7$	$S_8$	$S_9$
Normal stresses	0,198	0,250	0,315	0,397	0,500	0,630	0,794	1,000	1,260	1,587
Shear stresses	0,379	0,436	0,500	0,575	0,660	0,758	0,871	1,000	1,149	1,320

In determining the  $\lambda_i$ -values standardized spectra with a gaussian distribution of the load effects, the Miner rule and fatigue strength S-N lines with a slope  $m = 3$  for normal stresses and  $m = 5$  for shear stresses have been used.

In case the crane classification is not included in the specification documents of the crane indications are given in Annex B

Value of  $\lambda_i$  - accurate approach  
Function of kQ and C ( $\rightarrow$  #t / 73)

EN 1991-3 (2.17), (2.18)

$$\lambda_i = \sqrt[m]{(kQ C / N)}$$

$$kQ \rightarrow \#t / 73$$

$$C \rightarrow \#t / 73$$

$$N = 2 \cdot 10^6$$

$$m = 3 \text{ for } \Delta\sigma_E$$

$$m = 5 \text{ for } \Delta\tau_E$$

## Serviceability Limit States

$$\gamma = 1,0$$

Acceptable values of deflections and deformations of crane supporting structures will be presented on Lecture #4.

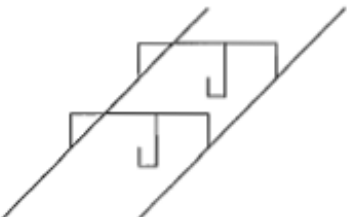
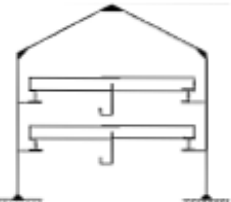
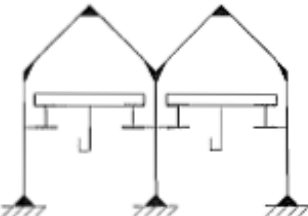
Type	$\gamma$
Dead weight of steel structure	1,35
Dead weight of crane	1,5
Weight of hoist load	
Acceleration of crane bridge	
Skewing of crane bridge	
Test load	
Buffer forces	
Loads on walkways...	
Wind	
Snow	
Tilting forces	
Guard rails	
Thermal action	
Actions during execution	
Accidental action	
Fatigue loads	$\gamma_{Ff}$ $\gamma_{Mf}$

Load and safety factors  
(for CC2)

## Combinations of loads

How many cranes we should take into consideration? → #t / 82

For which position of cranes on runbeam we have max values of cross-sectional forces? → #t / 83 - 87

Crane actions:	Cranes to each runway	Cranes in each shop bay	Cranes in multi-bay buildings	
				
Vertical	3	4	4	2
Horizontal	2	2	2	2

EN 1991-3 tab. 2.3

Recommended static scheme for runbeam: one-span beam, hinge supports.

Theoretically, we must take into consideration even three cranes for runbeams. But there is very important proportion between length of runbeam and length of crane.

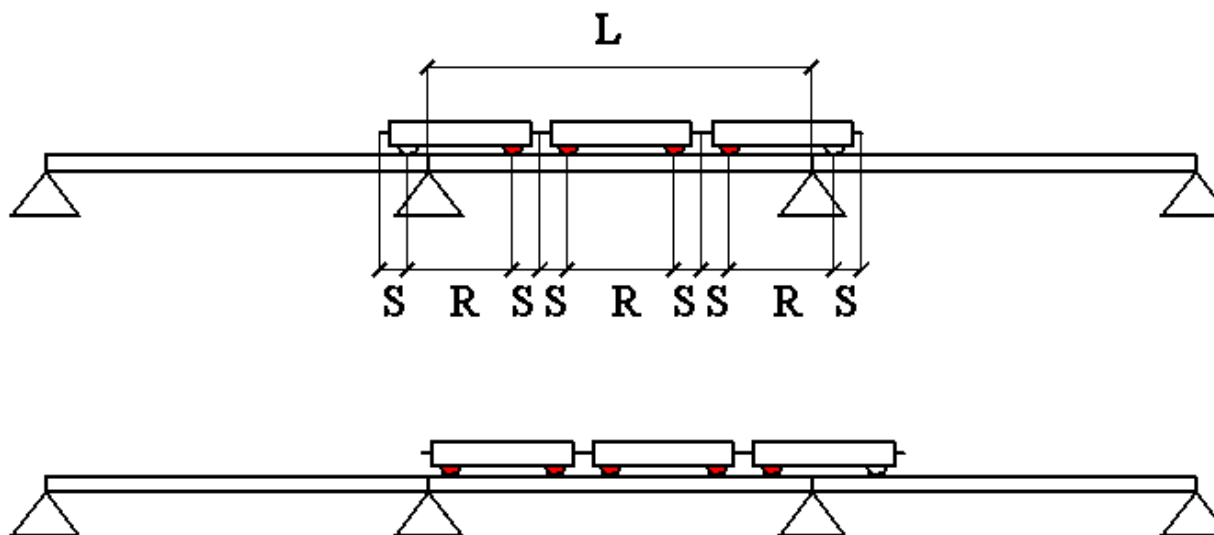


Photo: Author

We must take into consideration these wheels, which act on analysed runbeam only.

There are different loads on runbeams, according to different position of crab.

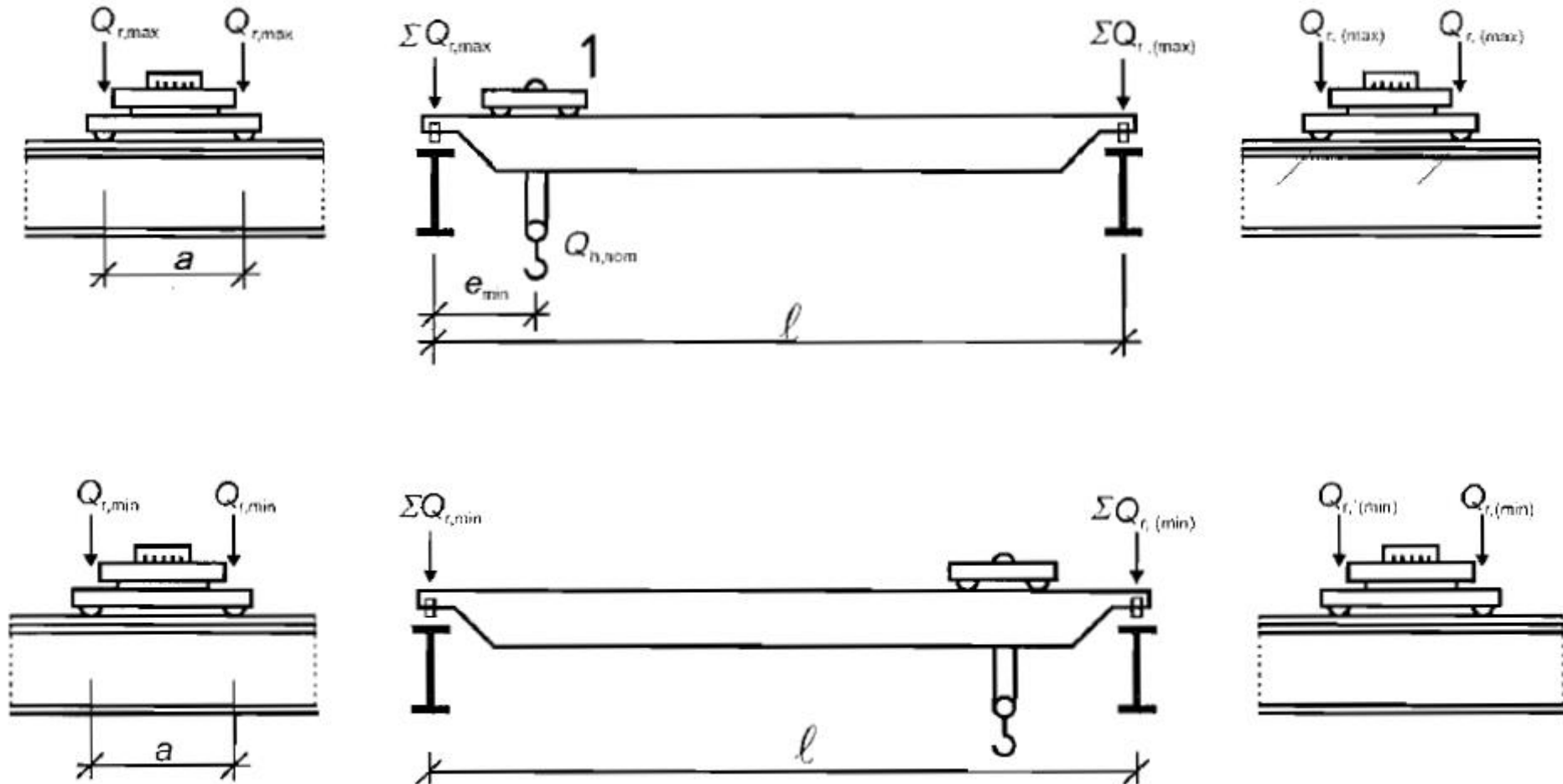
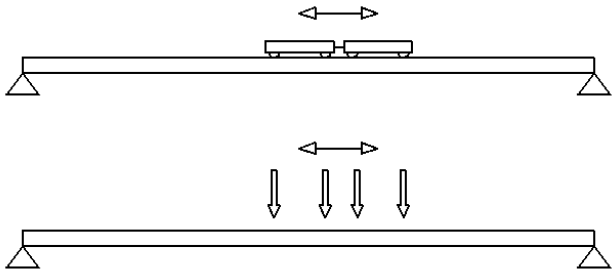


Photo: EN 1991-3 fig. 2.1

Photo: Author



Cranes can be rigid connected each other or work independently.

For both situation, cranes can't be closer each other than for rigid connection.

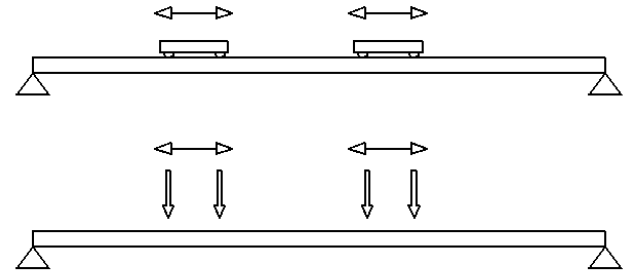
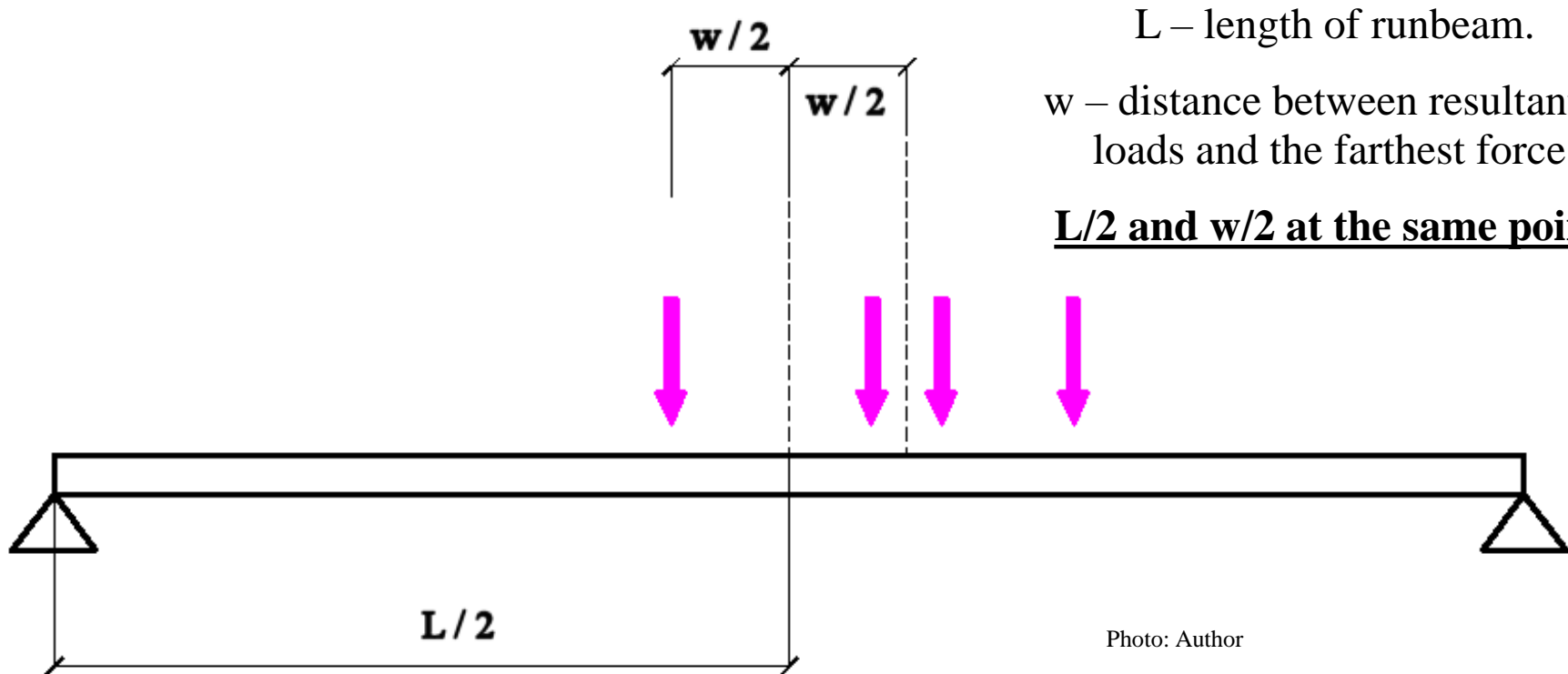


Photo: Author

Relative position of cranes is important for calculation max values of cross-sectional forces.



For this scheme, we have  $M_{\max}$  (Culman theorem)

Loads as close of support as possible.

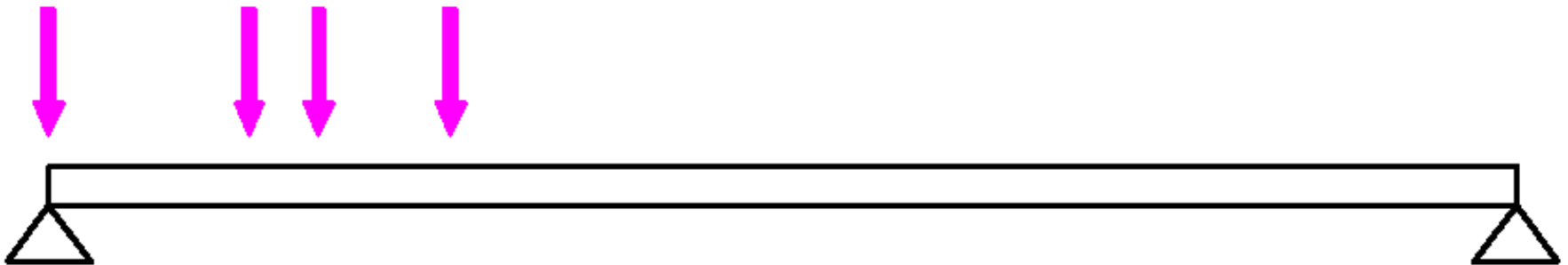


Photo: Author

For this scheme, we have  $R_{\max}$ ,  $V_{\max}$

Flange or not flange wheels are important for calculation of analysis horizontal loads, act from crane on rails, runbeams and supported structure.

Generally, horizontal contact wheels-rail and transport of horizontal loads from crane to runbeams exists for both runbeams, because of friction between wheel and rails.

Transport of horizontal loads from crane to runbeams is possible only when horizontal force is not greater than friction force ( $\mu \rightarrow$  #t / 37).

→ #t / 23

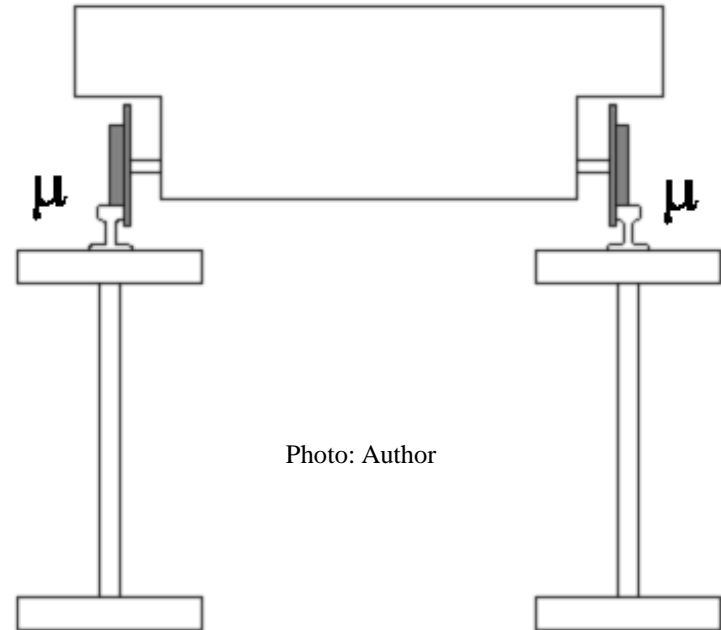


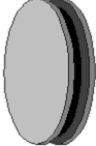


Photo: Author

EN 1993-6 5.6.2 (6) - horizontal forces can be applied to one or both runbeams:

Photo: Author

Loads	Type of wheel	
		
$H_{L,i} ; H_{T,i}$	both	
$H_{S,i, j, k}$	both	both
$H_{T3}$	one	both
$H_B$	both	both
$H_{B,2}$	both	both
$H_{TA}$	both	both
medium wind	one	both
strong wind	both	both

		Symbol	Section	Groups of load									
				ULS							Test load	Accidental loads	
				1	2	3	4	5	6	7			
1	Self-weight of crane	$Q_c$	2.6	$\varphi_1$	$\varphi_1$	1	$\varphi_4$	$\varphi_4$	$\varphi_4$	1	$\varphi_1$	1	1
2	Hoist load	$Q_h$	2.6	$\varphi_2$	$\varphi_3$	0	$\varphi_4$	$\varphi_4$	$\varphi_4$	$\eta$	0		
3	Acceleration of crane bridge	$H_L$ $H_T$	2.7	$\varphi_5$	$\varphi_5$	$\varphi_5$	$\varphi_5$	0	0	0	$\varphi_5$	0	0
4	Skewing of crane bridge	$H_S$	2.7	0	0	0	0	1	0	0	0	0	0
...	...	...	...	...	...	...	...	...	...	...	...	...	...

EN 1991-3 tab. 2.2

In table only general information about combinations of loads is presented. Because of two values of wind velocity (average / strong), two directions of wind (Transverse / Longitudinal) and two position of crane ( $\max M_{Ed}$  /  $\max V_{ed}$ ) there is many dozens of combinations.

Groups of loads	V = 0 [m / s]		V = 20 [m / s]				V = 22 - 26 [m / s]			
			T		L		T		L	
	M <sub>max</sub>	R <sub>max</sub> , V <sub>max</sub>	M <sub>max</sub>	R <sub>max</sub> , V <sub>max</sub>	M <sub>max</sub>	R <sub>max</sub> , V <sub>max</sub>	M <sub>max</sub>	R <sub>max</sub> , V <sub>max</sub>	M <sub>max</sub>	R <sub>max</sub> , V <sub>max</sub>
1 ULS			+	+	+	+	+	+	+	+
2 ULS			+	+	+	+	+	+	+	+
3 ULS			+	+	+	+	+	+	+	+
4 ULS			+	+	+	+	+	+	+	+
5 ULS			+	+	+	+	+	+	+	+
6 ULS	+	+								
7 ULS	+	+								
8 Test			+	+	+	+	+	+	+	+
9 Acc.	+	+								
10 Acc.	+	+								
Fat	+	+								
Disp			+	+	+	+	+	+	+	+

Really, there are much more combinations  $\Sigma = 66$

## Examination issues

Dynamic factors, enumeration and explanation

Loads, enumeration and explanation

Wind action on crane supporting structures

Way of calculations of fatigue actions

Hoist block - wciągnik  
Overhead travelling crane - suwnica pomostowa  
Underslung crane - suwnica podwieszona  
Top-mounted crane - suwnica natorowa  
Crab - wózek suwnicy  
Crane bridge - pomost suwnicy  
Guidance means - elementy prowadzące  
Gantry crane - suwnica bramowa  
Crane supporting structure - estakada podsuwnicowa  
Hoist load - podnoszony ładunek  
Grab - chwytak  
Driver - napęd  
Buffer - zderzak  
Skewing - zukosowanie  
Tilting - wychylenie  
Resultant - wypadkowa  
Bay - nawa  
Spectrum factor - współczynnik widma obciążeń

Thank you for attention

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tmichal@pk.edu.pl

