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A Study on the Wedge Angle of the Rail Clamp according to the Design Wind Speed Criteria Change

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Abstract : *In cargo-working, it unavoidably happens that the quay crane slip along the rail and the container move from side to side. Especially, they involve a lot of risk in bad weather. The rail clamp is a mooring device to prevent that the quay crane slips along the rail due to bad weather or the wind blast while the quay crane do the cargo-working. And it will play a greater role in port container terminal integration and automation. To design the wedge type rail clamp, it is very important to determine the wedge angle. In this study, we expect that the design wind speed of the quay crane will change over 16m/s. Assuming that the design wind speed is 40m/s, we determined the proper wedge angle of the wedge type rail clamp for the 50ton class quay crane.*

Key words : *Cargo Handling System, Container Terminal, Design Wind Speed, Quay Crane, Rail Clamp, Wedge Angle*

1. Introduction

For the container handling in port has increased in company with the growth of the trade scale, the Ultra Large Container Ship, such as 12,000 TEU grade, is constructed and the size of a quay crane increases more and more.

As the container ship comes alongside the quay, the quay crane was moved and stopped along the rail to load and unload containers. In cargo-working, it unavoidably happens that the quay crane slip along the rail and the container move from side to side. Especially, they involve a lot of risk in bad weather.

The rail clamp is a mooring device to prevent that the quay crane slips along the rail due to bad weather or the wind blast while the quay crane do the cargo-working. And it will play a greater role in port container terminal integration and automation. Fig. 1 shows the assembly diagram of the rail clamp. The operating mechanism of wedge type rail clamp is as follows. First, the jaw pad clamps a rail as a small clamping force. Second, the roller rolls on the slope of the wedge as the wind speed increase and the last, the jaw pad clamps a rail with a large clamping force. So, to design the wedge type rail clamp, it is very important to determine the wedge angle. Fig. 2 shows the operating mechanism of the wedge type rail clamp.

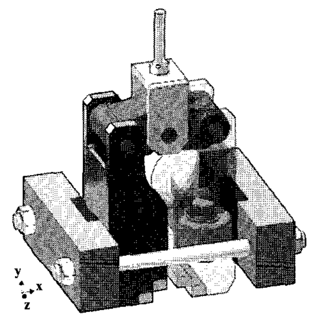
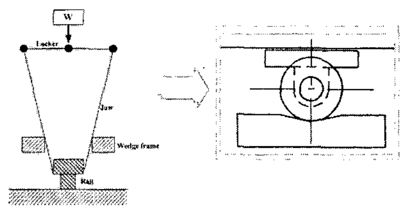
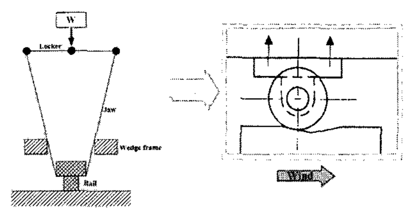


Fig. 1 Assembly diagram of the main part of the rail clamp



(a) initial



(b) clamping

Fig. 2 Operatiog mechanism of the wedge type rail clamp

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In this study, we expect that the design wind speed of the quay crane will change over 16m/s in operation mode due to unusual weather conditions. Assuming that the design wind speed is 40m/s, we determined the proper wedge angle of the wedge type rail clamp for the conventional quay crane.

2. Wind load analysis applied to the rail clamp

Two rail clamps are installed in the 50ton class quay crane and a rail clamp has two compression surfaces between the jaw pad and the rail. When the design wind speed of 40m/s is applied to the quay crane, the wind load, F_{ZZ} applied to the rail clamp is equal a quarter to the wind loads, F_Z applied to the quay crane. So, the wind load, F_{ZZ} applied to the rail clamp is calculated by Eq.(1).

$$F_{ZZ}=\frac{F_Z}{4}=\frac{C_{TZ}\times q_0\times A}{4} \tag{1}$$

Where, C_{TZ} is the rail direction coefficient of the wind force, q_0 is the wind pressure as $q_0=\frac{1}{2}\rho V_0^2(\frac{h}{20})^{0.16}$, V_0 is the wind speed, ρ is the air density, h is the height above ground, A is area normal to the wind direction. When the design wind speed of 40m/s is applied on the quay crane, the wind loads, F_Z applied to the quay crane is 1627.2 kN and the wind load, F_{ZZ} applied to the rail clamp is 406.8 kN by Eq.(1). So, the wind loads applied to the main part of the rail clamp are shown in Table 1. Wind loads are obtained by calculating the equation of Table. 1

Table 1 Wind loads applied to the main part of the rail clamp

Main Part	Symbol		Wind loads [kN]	
Jaw	F_P	F_L	813.6	271.2
Jaw pad	$F_P=F_Z/(4\mu)$		813.6	
Locker	$F_L=F_P(L_2/L_1)$		271.2	
Roller	$F_R=(F_P+F_L)/\cos\theta$		1101.5	
Wedge	$F_W=F_R$		1101.5	
Wedge Frame	$F_{Fn}=F_R\cos\theta$		1084.8	
	$F_{Ft}=F_R\sin\theta$		191.3	
Ext. Bar	$F_B=F_{Fn}/2$		542.4	

3. To determine the proper wedge angle

3.1 To determine the maximum wedge angle

1) Equilibrium condition between the roller and the wedge

[Condition 1] The normal force, F_R that the roller compresses the slope of the wedge is equal to the resultant of the wind load, F_{ZZ} applied to the rail clamp and the compression force, F_B generated by the extension bar.

$$F_R\times\sin\theta=F_{zz} \tag{2}$$

2) Condition to prevent that the jaw slip along the rail

[Condition 2] The friction force, μF_P between the jaw pad and the rail that is generated by the rail direction force, F_{Rt} of the roller calculated from the condition 1 must be equal to or greater than the wind load, F_{ZZ} applied to the rail clamp.

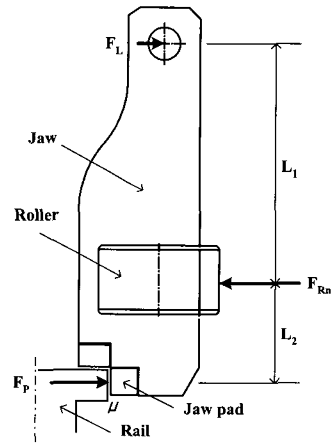
$$\mu F_p\geq F_{zz} \tag{3}$$

Eq.(4) that shows the relation between F_R and F_P is obtained by the Eq.(2), (3).

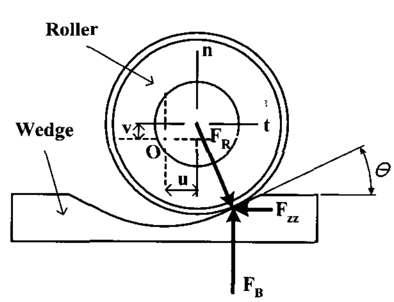
$$F_p=\frac{L_1}{L_1+L_2}\frac{F_R}{\cos\theta} \tag{4}$$

So, from Eq.(2), (3), (4) the wedge angle, θ_{CT} to prevent that the jaw slip along the rail is obtained like the Eq.(5).

$$\theta_{CT}\leq\tan^{-1}\left(\frac{\mu L_1}{L_1+L_2}\right) \tag{5}$$

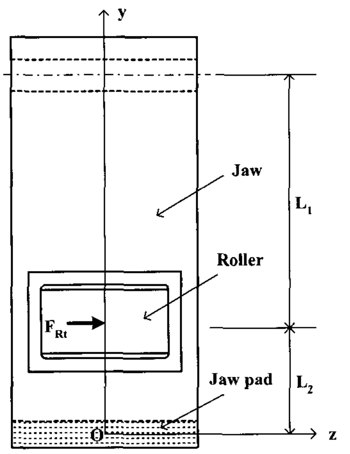


(a) Free body diagram of the jaw (x-direction)

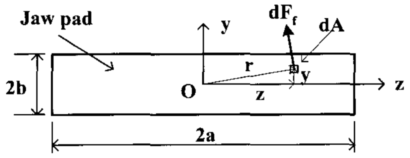


(b) Free body diagram between the roller and the wedge

Fig. 3 Free body diagram to determine the wedge angle to prevent that the jaw slip along the rail



(a) Free body diagram of the jaw (z-direction)



(b) Free body diagram of the jaw pad

Fig. 4 Free body diagram to determine the wedge angle to prevent that the jaw overturn along the rail

We could know the wedge angle, Θ_{CT} is related to the friction coefficient, μ between the jaw pad and the rail, the upper length, L_1 and the lower length, L_2 of the jaw. Fig. 3 shows the free body diagram of the rail clamp to determine the wedge angle to prevent that the jaw slip along the rail.

3) Condition to prevent that the jaw overturn along the rail

[Condition 3] The resistance moment, M_P of the jaw pad must be equal to or greater than the overturning moment, M_J of the jaw generated by the rail direction force, F_{Rt} of the roller.

$$M_P \geq M_J \tag{6}$$

The resistance moment, M_P of the jaw is

$$M_P = \frac{\mu G_P F_P}{A_P} \tag{7}$$

The overturning moment, M_J of the jaw is

$$M_J = F_{Rt} \times L_2 = \frac{L_2}{L_1}(L_1 + L_2) F_p \tan\Theta \tag{8}$$

So, from Eq.(6), (7), (8) the wedge angle, Θ_{CR} to prevent that the jaw overturn along the rail is obtained like the Eq.(9).

$$\Theta_{CR} \leq \tan^{-1}\left(\frac{\mu G_P}{A_P}\frac{L_1}{L_2(L_1+L_2)}\right) \tag{9}$$

Where, A_P is the area of the jaw pad, G_P is the moment of area as $G_P = \int_{-b}^{b}\int_{-a}^{a}\sqrt{z^2+y^2}\,dz\,dy$. Fig. 4 shows the free body diagram of the rail clamp to determine the wedge angle to prevent that the jaw overturn along the rail. And the dimensions of the jaw and the jaw pad are shown in Table 2.

Table 2 Dimensions of the jaw and the jaw pad

A_P	G_P	L_1	L_2
7000 ㎟	36690 ㎣	315 ㎜	105 ㎜

3.2 To determine the minimum wedge angle

As shown in Fig. 2 (b), the minimum wedge angle is determined by the relation between the horizontal clamping distance, $L_B(u)$ and the total displacements, $\delta_T(v)$ of the main part. The total displacements, δ_T of the main part of the rail clamp are

$$\delta_T = \frac{L_1}{L_1+L_2}(\delta_J + \delta_P) + \frac{L_2}{L_1+L_2}\delta_L + (\delta_R + \delta_W)\cos\Theta + \delta_F + \delta_B \tag{10}$$

Where, δ_J is the displacement of the jaw, δ_P is the displacement of the jaw pad, δ_L is the displacement of the locker, δ_R is the displacement of the roller, δ_W is the displacement of the wedge, δ_F is the displacement of the wedge frame, δ_B is the displacement of the extension bar. So, from the Eq.(10) the minimum wedge angle, Θ_{CL} of the rail clamp is

$$\Theta_{CL} = \tan^{-1}\left(\frac{\delta_T}{L_B}\right) \tag{11}$$

But substituting the displacement of the main part obtained by carrying out the Finite Element Analysis with ANSYS 8.1 to Eq.(10) we calculated the total displacements, δ_T of the main part of the rail clamp.

1) Analysis model of the rail clamp

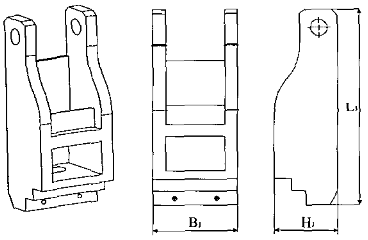
The rail clamp consists of 7 parts such as jaw, jaw pad, locker, roller, wedge, wedge frame, extension bar. The jaw is the part supported by the locker and plays a role of the lever. The jaw pad is the part that compresses the rail and adheres to the jaw. The locker is the part that generates the initial clamping force and connected with the jaw. The roller, wedge is the important part of the wedge type rail clamp that rolls on the slope of the wedge and increases the clamping force as the wind speed increases. The wedge frame is the part that supports the wedge. The extension bar is the part that generates the clamping force according to the total displacements. Table 3 shows the dimensions of the jaw, roller and wedge of the 50ton class quay crane and Fig. 5 shows the shape of the main part of the rail clamp.

Table 3 Dimensions of the jaw, roller and wedge

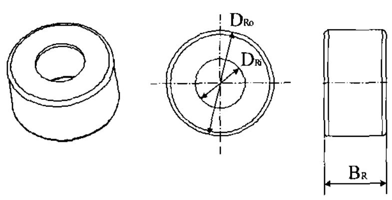
Jaw	B_J	H_J	L_J
	200 mm	150 mm	485 mm
Roller	B_R	D_{Ro}	D_{Ri}
	75 mm	60 mm	130 mm
Wedge	B_W	B_H	L_W
	150 mm	25 mm	162 mm

2) Finite Element Analysis

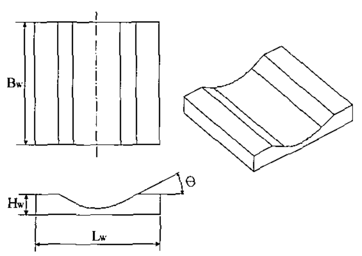
Element used in this analysis is 3-D 10-Node Tetrahedral Structural Solid element which have 3-DOF (U_X, U_Y, U_Z) at each node. Carrying out the Finite Element Analysis with ANSYS 8.1, we obtained the meshed shape and the stress distribution of the main part of the rail clamp as shown in Fig. 6 and 7.



(a) Dimensions of the jaw

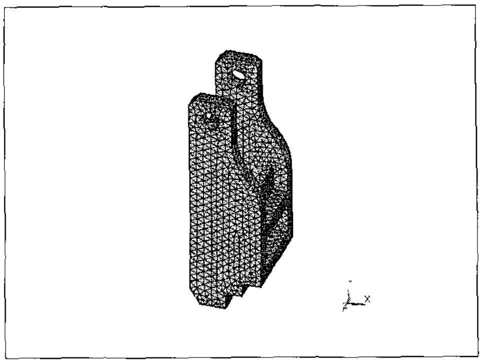


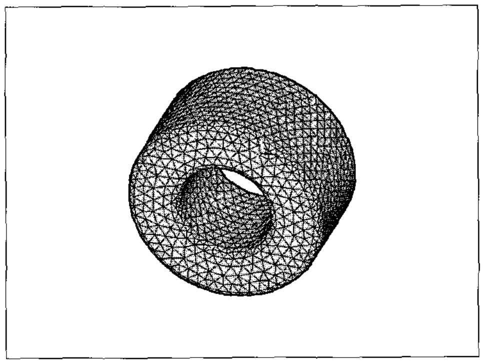
(b) Dimensions of the roller



(c) Dimensions of the wedge

Fig. 5 Shape of main part of the rail clamp


(a) meshed shape of the jaw


(b) meshed shape of the roller

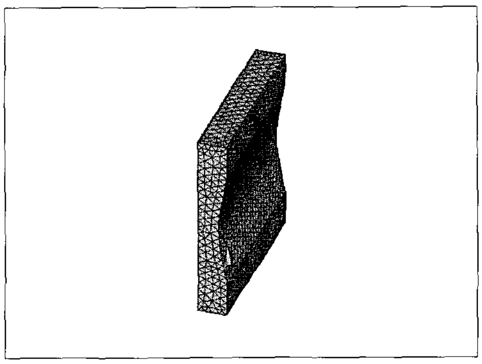
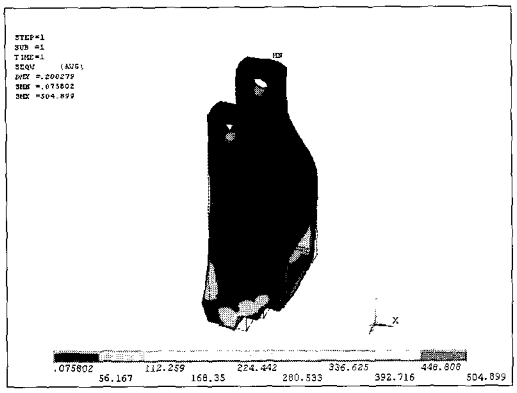

(c) meshed shape of the wedge

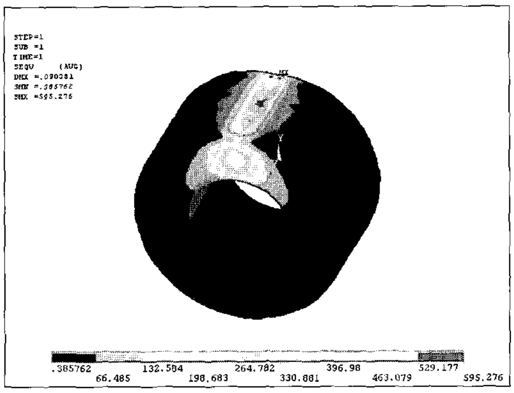
Fig. 6 Meshed shape of the main part of the rail clamp

The boundary conditions of the main part of the rail clamp are as follows. First, the boundary conditions of the jaw is applied ux, uy at the pin linking the jaw to the locker in the -X direction. And applied ux, uz at the pin linking the roller in the +X direction. Second, the boundary conditions of the roller is applied ux, uy at the pin linking the roller in the +Y direction. The last, the boundary conditions of the wedge is applied ux, uy at the area of contact with the wedge frame in the +X direction and uy at the area of contact with the wedge frame in the +Y direction.

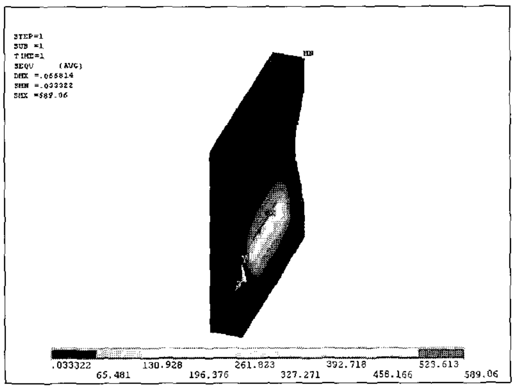
The load condition of the jaw is applied F_P=813.6 kN. And the load condition of the roller is applied F_W=1101.5 kN. The load condition of the wedge is applied F_R=1101.5 kN.



(a) stress distribution of the jaw



(b) stress distribution of the roller



(c) stress distribution of the wedge

Fig. 7 Stress distribution of the main part of the rail clamp

4. Results and Discussions

4.1 the maximum wedge angle of the rail clamp

Substituting μ is 0.5, L_1 is 315mm and L_2 is 105mm to Eq.(5), we knew the wedge angle, θ_{CT} to prevent that the jaw slip along the rail is equal to or less than 20.6°.

And substituting A_P is 7000mm^2, G_P is 361690 mm^3 to Eq.(9), we knew the wedge angle, θ_{CR} to prevent that the jaw overturn along the rail is equal to 10.5°.

Therefore, Considering the wedge angle, θ_{CT} to prevent that the jaw slip along the rail and the wedge angle, θ_{CR} to prevent that the jaw overturn along the rail, we determined the maximum wedge angle of the rail clamp for the 50ton class quay crane is 10.5°.

4.2 the minimum wedge angle of the rail clamp

Carrying out the Finite Element Analysis with ANSYS 8.1, we obtained the strength and displacements analysis results of the main part of the rail clamp as shown in Table 4, 5. Substituting the displacement of the main part to Eq.(10), we knew the total displacements, δ_T of the main part of the rail clamp is 1.879mm. And we determined the minimum wedge angle, θ_{CL} of the rail clamp for the 50ton class quay crane is 4.3°. Where, the horizontal clamping distance, L_B is 25mm.

As the total displacements is 1.879mm, the minimum wedge, θ_{CL} of the rail clamp for the 50ton class quay crane with respect to the clamping distance, L_B are shown in Table 6. As shown in Table 6, we knew the minimum wedge angle, θ_{CL} of the rail clamp for the 50ton class quay crane decreases with the clamping distance, L_B.

Table 4 Strength results of the main part of the rail clamp

Main Part	Stress[MPa]		Safety Factor	Material
	Yield	Maximum		
Jaw	823	504.90	1.63(≥1.50)	SCM445
Jaw pad	744.8	528.50	1.41(≥1.15)	SCM435
Locker	400	194.60	2.06(≥1.15)	SS540
Roller	744.8	595.28	1.25(≥1.15)	SCM435
Wedge	705.6	589.06	1.20(≥1.15)	SCM432
Wedge Frame	400	270.25	1.66(≥1.50)	SS540
Ext. Bar	784	399.64	1.96(≥1.50)	SCM440

Table 5 Displacement of the main part of the rail clamp

Main Part	Symbol	Displacement
Jaw	δ_J	0.200 mm
Jaw pad	δ_P	0.048 mm
Locker	δ_L	0.037 mm
Roller	δ_R	0.090 mm
Wedge	δ_W	0.067 mm
Wedge Frame	δ_F	0.197 mm
Ext. Bar	δ_B	1.332 mm

Table 6 Minimum wedge angle with respect to the clamping distance

L_B	15mm	20mm	25mm	30mm	35mm
θ_{CL}	7.1°	5.4°	4.3°	3.6°	3.1°

4.3 the proper wedge angle of the rail clamp

The maximum wedge angle of the rail clamp for the 50ton class quay crane is 10.5°. and the minimum wedge angle is 4.3°. So, we should determine the proper wedge angle of the rail clamp for the 50ton class within the limit of the wedge angle. Therefore, considering the maximum and minimum wedge angle, we determined the proper wedge angle is 10°. Since the wedge angle is larger, the clamping efficiency of the rail clamp is higher.

5. Conclusions

In this study, the design wind speed of the quay crane is expect to change over 16m/s in operation mode due to unusual weather conditions. Assuming that the design wind speed is 40m/s, we determined the proper wedge angle of the wedge type rail clamp for the 50ton class quay crane. and the results are as follows.

The proper wedge angle of the rail clamp for the 50ton class quay crane is determined with the limit of the maximum and minimum wedge angle. The maximum wedge angle is obtained by the condition to prevent that the jaw slip along the rail and overturn along the rail. The wedge angle, θ_{Cr} to prevent that the jaw slip along the rail is equal to or less than 20.6°. And the wedge angle, θ_{CR} to prevent that the jaw overturn along the rail is equal to or less than 10.5°. The minimum wedge angle of the rail clamp for the 50ton class quay crane is 4.3°. We determined the proper wedge angle of the rail clamp is 10°. Since the wedge angle is larger, the clamping efficiency of the rail clamp is higher.

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