A Study on the Sliding Distance and the Proper Position of Supporter with respect to the Wedge Angle in the Wedge Type Rail Clamp

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ABSTRACT

The rail clamp is the device to prevent the crane slips along rails from the wind blast as well as to locate a container crane in the set position in operating mode. In this study we conduct the research for the sliding distance of rail clamp and the proper position of supporter with respect to the wedge angle in the wedge type rail clamp. The sliding distance to display the clamping force of the jaw pad corresponding to the design wind speed criteria is determined by the total displacement of the rail clamp at the roller center and the wedge angle. And the supporter is the device to prevent the overload which is applied on each part of the rail clamp by wind speed increment, because a clamping force is generated by the sliding of the wedge due to the wind. Accordingly the position of the supporter to prevent the overload is determined by analyzing the forces applied to the rail clamp. In order to analyze the sliding distance and the proper position of supporter with respect to the wedge angle as the wind speed is 40m/s, 5-kinds of wedge angles, such as 2, 4, 6, 8, 10°, were adopted as the design parameter.

1. Introduction

A container crane operates under weakness condition which has no shielding facility to protect a container crane from wind blast. Recently, the maximum instantaneous wind speed is increasing more and more due to climate change by El-Nino and La-Nina (KMA, 2005). The increase of the maximum instantaneous wind speed bears the increase of an overturning moment and z-directional (tangent directional to rail) force for a container crane, and then causes a container crane to collapse. The design wind speed criteria were intensified from the wind speed of 20m/s to 40m/s during an operating mode, and from 50m/s to 70m/s during a stowed mode in Korea, according to the 'Management Regulation for Facilities and Equipments in Port' (MOMA&F, 2004) amended after the accident of a container crane due to the typhoon 'Maemi.'

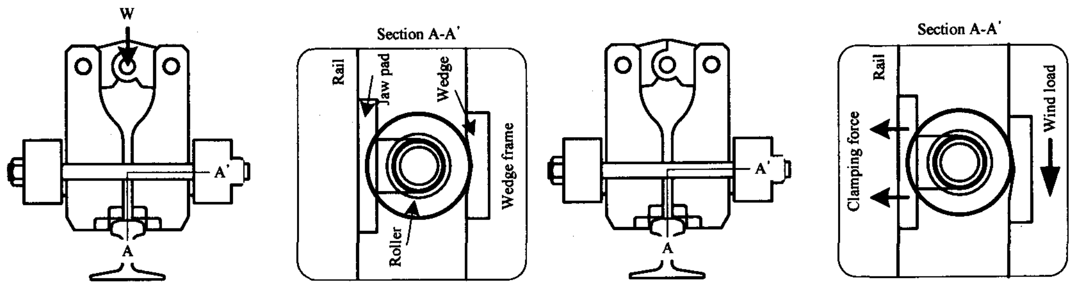
When the containership comes alongside the quay, the container cranes reiterate a move and a stop along rails to load and unload containers on the vessel during an operating mode. When the large z-directional wind load is generated by a wind blast applies to the container crane in an operating mode, if the breaking devices of the crane are out of order, the crane will run along a rail and bring about a huge accident. So in an operating mode, the rail clamps are used to prevent that the crane slips along rails due to the wind blast (Ha, 2003). The rail clamp is very important device to prevent that a container crane slips along a rail due to the wind blast as well as to locate the crane in the set position during an operating mode (Oh, 2000). The wedge type rail clamp compresses the rail side with small clamping force in initial clamping stage, and as the wind speed increases, the clamp compresses the rail side with large clamping force by the wedge working.

The wedge type rail clamp has a different operating mechanism according to the operating stages. So we have to design the rail clamp after divide the operating stage into two stages, such as the initial clamping stage, that two jaw pads compress both rail sides with small clamping force, and the wedge working stage, that the clamping force of the jaw pad increases due to a wedge as the wind speed increases (Han et al, 2004). In this study we dealt with the latter case. The clamping force of a jaw pad in the wedge working stage is increased by the wedge working, that a roller rolls along the slope of a wedge, as the wind speed increases. In this time, the sliding distance of a wedge for the wedge working varies with respect to the wedge angle, and if the supporter to prevent that a roller rolls infinitely along a slope of a wedge isn't installed, the overload will apply to parts of the rail clamp when the wind speed increases and finally the device will be broken down. Therefore we analyzed the relationship between the sliding distance and the wedge angle carrying out the finite element analysis, and determined the proper position of the supporter so that the clamping force of the jaw pad may be less than the force corresponded to the wind speed of 40m/s.

2. Relationship between the Wedge Angle and the Sliding Distance of the Rail Clamp

2.1 Operating Mechanism of the Wedge Type Rail Clamp

The operating mechanism of the wedge type rail clamp is largely divided into three stages, such as an open stage, an initial clamping stage, and a wedge working stage as shown in Fig. 1.



(a) initial clamping stage (b) wedge working stage

Fig. 1 Operating mechanism of the wedge type rail clamp

The operating method in the initial clamping stage: At first both lockers are dropped downward by the weight of heavy pendulum (W), and both upper jaw pads bump against the top face of a rail. And then continually the angle of a locker is decreased and then both side jaw pads bump against the side of a rail. At last the initial clamping force occurs.

The operating method in the wedge working stage: At first the z-directional wind load (F_z) applied to the container crane increases, as the wind speed increases, and then a wedge frame fixed in the crane moves into the rail direction. At last if a wedge built-in the wedge frame moves into a rail direction, the wedge working, that a roller connected with a jaw rolls along the slope of a wedge, will be generated and increase the clamping force of both side jaw pads.

2.2 Relationship between the Wedge Angle and the Sliding Distance of the Rail Clamp

The free body diagram of a roller and wedge in the wedge working stage was shown in Fig. 2.

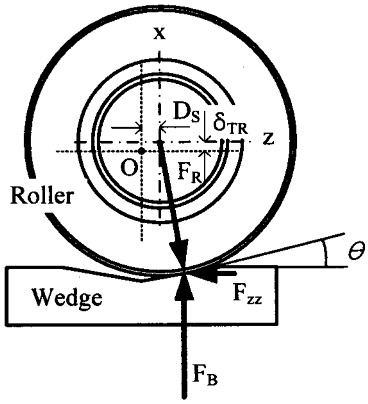


Fig. 2 Total x-directional deformation and sliding distance in the roller center of a wedge type rail clamp

As shown in Fig. 2, the sliding distance (D_S) to display the clamping force of the jaw pad (F_P) corresponding to the design wind speed criteria is determined by the total displacement of the rail clamp (δ_{TR}) at the roller center and the wedge angle (θ).

$$D_S = \delta_{TR} \cot\theta \tag{1}$$

If the wind speed increases, the displacement of main part of the rail clamp will increase, and then the roller will roll on the wedge slope as the total displacement at the roller center. In this time, the z-directional displacement of the roller center becomes the sliding distance. Accordingly, the sliding distance of the wedge type rail clamp is obtained by the total displacement calculated from the results of the finite element analysis for 7 component parts of the rail clamp. The x-directional displacements of a jaw, a jaw pad, and a locker have positive value (+), and the x-displacements of a roller, a wedge, a wedge frame, and a extension bar have negative value (-) on the basis of roller center. So the total x-directional displacement at the roller center could be represented as follows.

$$\delta_{TR} = \left\{ \delta_{JR} + \frac{(L_{JU}\delta_P + L_{JL}\delta_L)}{L_{JU} + L_{JL}} \right\} - \{(\delta_R + \delta_W)\cos\theta + \delta_F + \delta_B\} \quad (2)$$

where, δ_{JR} is the x-directional displacement of a jaw at the position where the roller is attached to, δ_P is it of the jaw pad, δ_L is it of the locker, δ_R is it of the roller, δ_W is it of the wedge, δ_F is it of the wedge frame, δ_B is the displacement of the extension bar, and L_{JU} and L_{JL} are the upper and lower length of a jaw.

3. Finite Element Analysis for the Main Part of the Rail Clamp with respect to the Wedge Angle

3.1 Analysis Model

In order to obtain the x-directional displacement for main part of the wedge type rail clamp for 50tons-class container crane with respect to the wedge angle, the stiffness analysis on 7 component parts was carried out using the ANSYS Workbench which is the universal finite element analysis program. The element used in analysis is the hex-dominant which is five nodes pyramid element, and the maximum length of a side of element was set up as maximum 10mm to be an error of 5% or below. And the meshed shape for the main part of the rail clamp was shown in Fig. 3.

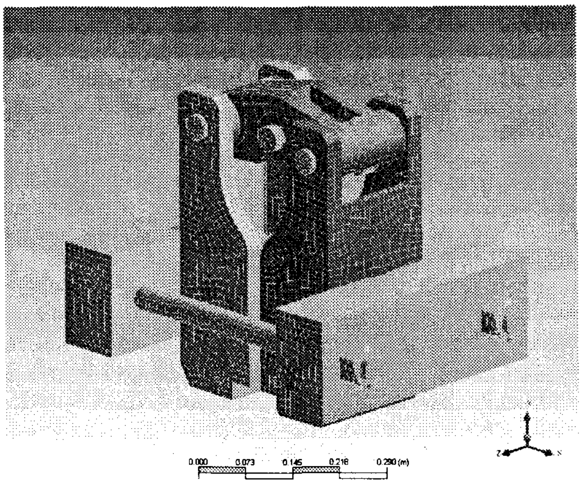


Fig. 3 Meshed shape of main part in the wedge type rail clamp

In order to compute the total x-directional displacement at the roller center, the parts of the rail clamp were largely divided into two assembly parts, such as the jaw part which consists of a jaw, a locker, and a jaw pad, and the wedge part which consists of a roller, a wedge, a wedge frame, and a extension bar, because the x-directional displacements of a jaw, a jaw pad, and a locker have positive value (+), and the displacements of a roller, a wedge, a wedge frame, and a extension bar have negative value (-) on the basis of roller center.

3.2 Design Parameter and Load Condition

In order to evaluate the sliding distance of the wedge type rail clamp with respect to the wedge angle in the wind speed of 40m/s, 5-kinds of wedge angles, such as 2, 4, 6, 8, 10°, were adopted as the design parameter, because the maximum wedge angle is 10.9° from previous paper by Han (2004). According to BS2573, the z-directional wind load (F_z) of 50tons-class container crane with respect to the design wind speed (V_0), was determined as follows (Hanjin HI&C Co. Ltd., 2000).

$$F_z = 1.017 \times V_0^2 \quad [kN] \quad (3)$$

And the forces applied to the 7 component parts of the rail clamp with respect to the wedge angle as the wind speed is 40m/s were calculated and shown in Table 1 (Lee et al, 2005). The forces applied to the roller, the wedge, and wedge frame changes as the wedge angle changes, but others don't change, because these are unrelated to the wedge angle.

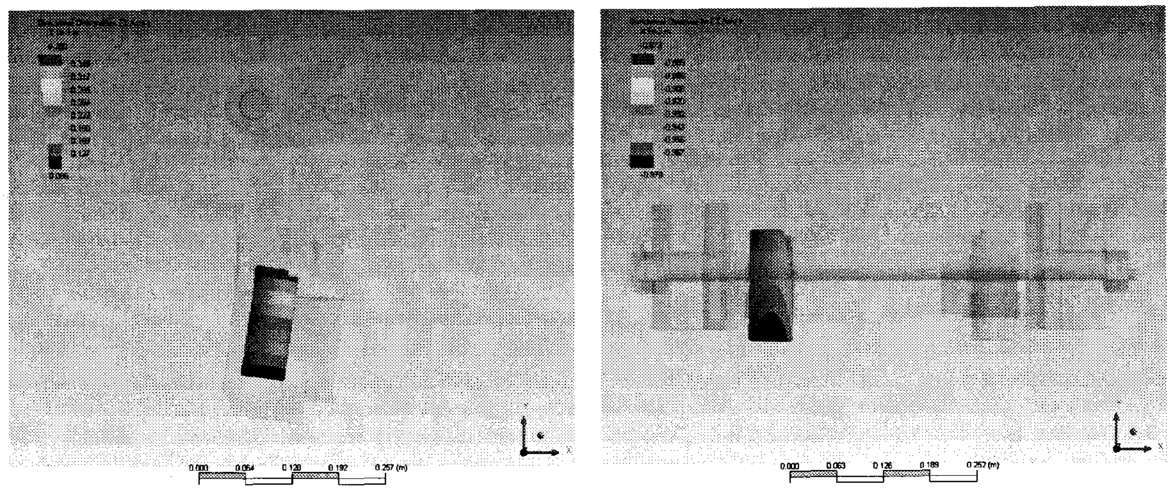
Table 1 Forces applied to 7 component parts of the wedge type rail clamp with respect to the wedge angle (as V_0=40m/s) [unit : kN]

Forces	θ [°]				
	2	4	6	8	10
F_P	813.275	813.275	813.275	813.275	813.275
F_L	301.461	301.461	301.461	301.461	301.461
F_{Rx}	1114.736	1114.736	1114.736	1114.736	1114.736
F_{Rz}	38.927	77.950	117.163	156.666	196.558
F_R	1115.416	1117.458	1120.876	1125.691	1131.933
F_B	557.368	557.368	557.368	557.368	557.368

4. Results and Discussions

4.1 Sliding Distance of the Rail Clamp with respect to the Wedge Angle

The x-directional displacement distributions of two assembly parts, when the wedge angle is 10°, were shown in Fig. 4, and the x-directional displacements of two assembly part at the roller center were shown in Table 2.



(a) jaw part (b) wedge part

Fig. 4 X-directional displacement distribution at the center of roller pin in the wedge type rail clamp (as θ=10°, V_0=40m/s)

Table 2 X-directional displacements at the center of roller pin of 7 component parts of the wedge type rail clamp with respect to the wedge angle (as V_0=40m/s) [unit : mm]

Response	θ [°]				
	2	4	6	8	10
$\delta_{RP,\ Jaw\ part}$	0.238	0.238	0.238	0.238	0.238
$\delta_{RP,\ Wedge\ part}$	-0.901	-0.897	-0.890	-0.898	-0.926

In Table 2, the x-directional displacement of the jaw part ($\delta_{RP,\ Jaw\ part}$) at the roller center is equal to a former brace in Eq. (2) and the displacement of the wedge part ($\delta_{RP,\ Wedge\ part}$) is equal to a latter brace. The x-directional displacement of the jaw part appeared uniform as 0.238mm as the wedge angle increases from 2° to 10°, because the forces applied to the jaw, the jaw pad, and the locker are uniform regardless of the wedge angle. The other side, the x-directional displacement of the wedge part appeared as -0.901, -0.897, -0.890, -0.888, -1.153mm respectively as the wedge angle increases from 2° to 10°. That means that the effect of the wedge angle on the x-directional displacement of the wedge part is very small.

Calculating the total x-directional displacement of the rail clamp (δ_{TR}) at the roller center using Eq. (2) and substituting the results into Eq. (1), the sliding distance of the wedge type rail clamp (D_S) with respect to the wedge angle (θ) in the wind speed of 40m/s is obtained. Table 3 shows the total x-directional displacement of the rail clamp at the roller center and the sliding distance with respect to the wedge angle.

Table 3 Total x-directional displacement at the center of roller pin and sliding distance of the wedge type rail clamp with respect to the wedge angle (as V_0=40m/s) [unit : mm]

Response	θ [°]				
	2	4	6	8	10
δ_{TR}	1.139	1.135	1.128	1.136	1.164
D_S	32.62	16.23	10.73	8.08	6.60

In Table 3, the total x-directional displacement of the rail clamp at the roller center appeared as 1.139, 1.135, 1.128, 1.136, 1.164mm respectively as the wedge angle increases from 2° to 10°. But the change of the values was insignificant on the basis of 1.135mm. Therefore the sliding distance of the rail clamp (D_S) for 50tons-class container crane with respect to the wedge angle (θ) in the wind speed of 40m/s could be represented as the cotangent function with respect to the wedge angle from Eq. (1).

$$D_S = 1.135\cot\theta \tag{4}$$

4.2 Position of the Supporter to prevent the Overload

The proper position of the supporter to prevent the overload is determined by analyzing the forces applied to the rail clamp in the wedge working stage. The friction force (F_{fP}) between the jaw pad and the rail to prevent that the crane slips along the rail, when the wind blows, is generated by the z-directional wind load (F_z). Accordingly the friction force (F_{fP}) between the jaw pad and the rail according to the z-directional wind load (F_{zz}) applied to a wedge is as follow.

$$F_{fP} = \frac{L_{JU}}{L_{JU}+L_{JL}}\frac{\mu_P}{\tan\theta}F_{zz} \tag{5}$$

In Eq. (5), we could know that the friction force between the jaw pad and the rail becomes only the function with respect to the wedge angle (θ), when the ratio of the upper length for the total length of the jaw ($L_{JU}/(L_{JU}+L_{JL})$) and the friction coefficient (μ_P) between the jaw pad and the rail are made an offer determined.
Because the z-directional wind load (F_z) when the wind speed is 40m/s is 1,627.5kN from Eq. (3), the wind load (F_{zz}) of which a jaw pad takes charge becomes 406.6kN. Fig. 5 shows the wind load (F_{zz}) applied to a wedge and the friction forces (F_{fP}) between the jaw pad and the rail when the wedge angle is 2, 4, 6, 8, 10°.

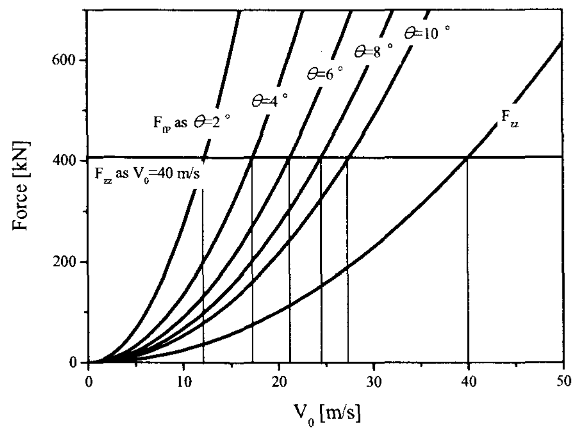


Fig. 5 wind load and friction force between the jaw pad and a rail with respect to the wind speed and the wedge angle

If the wedge angle is 20.54° which is the critical wedge angle to prevent that the jaw pad slips along the raill, the curve of the friction force will agree with the curve of the wind load. But the friction force of the jaw pad at

an arbitrary wedge angle (θ) is always larger than the wind load applied to a wedge as shown in Fig. 5, because the maximum critical wedge angle was set up as 10.9° from the condition to prevent that the jaw overturns. That means that the friction force of the jaw pad come up to the wind load corresponding to the wind speed is 40m/s, before the wind speed is arrived at 40m/s. Namely if the supporter isn't exist, the roller will roll on the wedge slope continually. So if the wind speed is 40m/s, the overload which is larger than the design criterion will apply to 7 component parts of the rail clamp, and the parts of the rail clamp will be induced the fracture.
Accordingly the supporter must be installed in the wedge type rail clamp to cause no overload. The clamping force of the jaw pad (F_P) is generated by the strain energy due to the deformation of the main part. Therefore the position of supporter is equal to the sliding distance required in wind speed of 40m/s as shown in Table 3. Accordingly Eq. (4) can be utilized in determining the position of the supporter to prevent the overload applied to the main part of the wedge type rail clamp when the wind speed increases.

5. Conclusions

In this study we conducted the research for the sliding distance and the proper position of the supporter with respect to the wedge angle of the wedge type rail clamp for 50tons-class container crane in the design wind speed criteria of 40m/s. The stiffness analysis on the main part of the rail clamp was carried out using the ANSYS Workbench, and the results are as follows:

(1) We could know that the total x-directional displacement of the rail clamp at the roller center appeared as 1.139, 1.135, 1.128, 1.136, 1.164mm respectively as the wedge angle increases from 2° to 10°, but the change of the values was insignificant on the basis of 1.135mm. So the sliding distance of the rail clamp for 50tons-class container crane with respect to the wedge angle could present as the function of cotangent.

(2) We could know that the position of supporter is equal to the sliding distance required in wind speed of 40m/s. So the proper position of the supporter to prevent the overload applied to the main part of the wedge type rail clamp with respect to the wedge angle is as follows:

$$D_S = 1.135 \cot\theta$$

(3) Therefore the design formula for determining the proper position of the supporter suggested in this study will apply to design the various wedge type rail clamp.

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