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一般論文

Prediction of Fluctuation Tension of Securing Rope by Oscillation

Young-Du KIM* and Katsuhiko SAITO**

Abstract

It is very important that the transportation of cargo to the destination safely and on time. Especially, we need careful attention to carriage of cargo in case of the long-distance and marine transportation under a lot of external effects relatively. The cargo is received the influence of the outside and it is likely to move by the force even if it was fixed. To prevent transfer of cargo by the motion, we are securing the cargo with rope. But, a number of serious accidents has resulted from improper stowage and insufficient securing of cargo. Such an accident have occurred fatal damage to not only the cargo but also the ship. So, all operators must be reminded that only proper stowage and securing of cargos can prevent from the occurrence of such accidents in the future.

First of all, we thought only so called roll and heave motions and derived mathematical equations to calculate the force of securing rope. And then, was measured a change of the rope tension and motion of simulator at time series. Finally, predicted the fluctuation tension of the rope in case of arbitrary initial tension and frequency using the measured data. Also, the results of prediction were verified through the experiment.

Keywords: Securing, Fluctuation Tension, Oscillation

1. Introduction

IMO has published Code of Safe Practice for Cargo Stowage and Securing and put it to good use by connected group [1-2]. But this code was only recorded basic stowage and securing method by kind of each transport cargo. Base on this, IMO recommended a marine company and classification society to draw up a suitable cargo securing and stowage manual, guideline respectively. But, the most of research was the optimum loading of stowage, the lashing method of securing rope and strength of container [3-8].

To prevent from movement of cargo is used a lot of equipment. The transformation of cargo may be occurred because of external force to receive under transportation. If there is

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not a change of tension of securing rope, cargo will be arrived at a destination safely. But, the tension of securing rope might be changed by the external force and be occurred the movement accidents of the cargo.

Moreover, the initial tension of the ropes by the securing work is adjusted by experience of the field worker's and there becomes a difference by a person.

It is necessary to the securing to go to the destination safely at the first time work. In order to maintain the tension of rope and prevent the cargo movement accidents, we must check out the securing rope at all times. But it can be difficult to check the general condition and tension of rope in transport. Also, if necessary, it will be replaced with a new one in the bad condition rope.

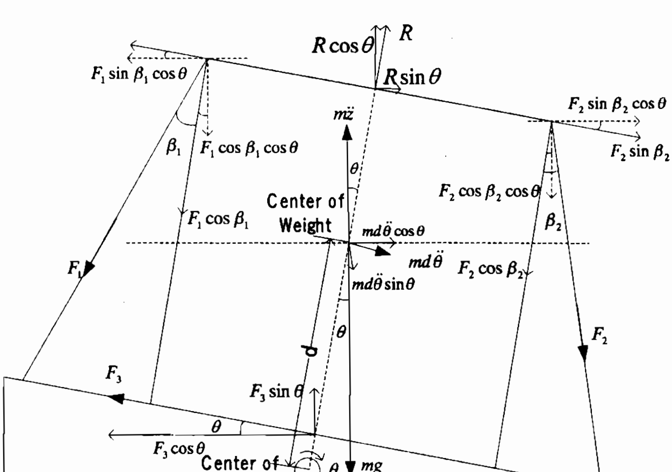
Thus the initial tension decision is very important and operators of cargo must be reminded that only proper securing of cargoes can prevent from the occurrence of such accidents in the future.

In the research, we carried out an experiment on using of the motion simulator. Previously, compare the prediction with the experiment of the fluctuation tension by the motions.

2. Mathematical formula

2.1 Balance of forces

Fig.1 shows the forces acting on the object fixed on the roll and heave motions. The balance of forces can be thought out the vertical direction and horizontal direction, as follows.



Where,
F_1, F_2 : Tension of rope
F_3 : Frictional force, β_1, β_2 : Angle of rope
R : Drag force, m : Mass of box
g : Gravitational acceleration
d : Vertical distance between the center of motion and the center of weight
$\theta = \Theta\sin(\omega_\theta t + \varepsilon_\theta)$: Displacement of roll motion
$z = Z\sin(\omega_z t + \varepsilon_z)$: Displacement of heave motion
$\ddot{\theta}, \ddot{z}$: Acceleration of roll and heave motion
Θ, Z : Amplitude of roll and heave motion
$\varepsilon_\theta, \varepsilon_z$: Phase angle of roll and heave motion
ω_θ, ω_z : Angular frequency of roll and heave motion

Fig. 1 Balance of forces between vertical direction and horizontal direction by the motion

・Vertical direction

$$R\cos\theta + m\ddot{z} + F_3 \sin\theta = mg + F_1\cos\beta_1\cos\theta + F_2\cos\beta_2\cos\theta + md\ddot{\theta}\sin\theta \tag{1}$$

・Horizontal direction

$$F_1\sin\beta_1\cos\theta + F_3\cos\theta = R\sin\theta + F_2\sin\beta_2\cos\theta + md\ddot{\theta}\cos\theta \tag{2}$$

According to numerical formula (1, 2), the drag and the frictional force of securing can be shown as follows.

・Drag Force (R)

$$R = \cos\theta\,(mg + F_1\cos\beta_1\cos\theta + F_2\,\mathrm{cs}\beta_2\cos\theta - m\ddot{z}) - \sin\theta\,(F_2\sin\beta_2\cos\theta - F_1\sin\beta_1\cos\theta) \tag{3}$$

・Frictional Force (F_3)

$$F_3 = \sin\theta\,(mg + F_1\cos\beta_1\cos\theta + F_2\cos\beta_2\cos\theta + md\ddot{\theta}\sin\theta - m\ddot{z}) + \cos\theta\,(F_2\sin\beta_2\cos\theta + md\ddot{\theta}\cos\theta - F_1\sin\beta_1\cos\theta) \tag{4}$$

2.2 Fluctuation tension (ΔF)

If an initial tension and the amount of the change of $F_1\,(F_2)$ are called $F_{01}\,(F_{02})$ and ΔF_1 (ΔF_2) respectively and $\beta_1 = \beta_2 = \beta$, $\Delta F_1 = \Delta F_2 = \Delta F$. $F_{01} = F_{02} = F_0$. (in formula (4), replace F_1. F_2 with$F_0 + \Delta F$, $F_0 - \Delta F$), the fluctuation tension is written as below.

$$\Delta F = \frac{1}{2\sin\beta\cos^2\theta}\left\{\sin\theta\ (mg + 2F_0\cos\beta\cos\theta - m\ddot{z}) - F_3 + md\ddot{\theta}\right\} \tag{5}$$

In this time, we thought only rolling motion. So, only the frictional force is necessary for the prediction of the fluctuation tension. Look at the formula (4), the frictional force can be got simply because other factors are possible to measure.

3. Fluctuation tension of securing rope

In order to predict of rope tension by the motion, we must understand change drag and frictional force to act on an object previously. However, these are not measured in the reality.

Therefore, if understand the relation between floor material and object material, rope material and rope arrangement, initial tension and effect by relativity relation of time series, the tendency of frictional force can be requested through to experiment. In that event, it is possible to predict of the fluctuation tension of securing rope.

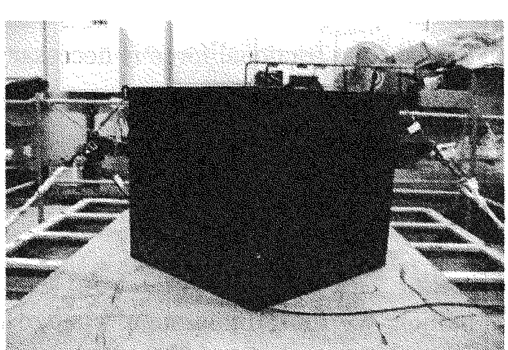
3.1 Condition of Experiment

The condition of experiment apparatus is as following.

- Frequency of motion simulator : 0.1, 0.2, 0.3Hz
- Inclined angle of rolling : $\pm 5^{\circ}$, $\pm 10^{\circ}$
- Initial tension of rope : 2.5, 5.0, 10.0×9.8(N)
- Type and diameter of rope : Vinylon ϕ 12, 9, 6mm, Cotton ϕ 9mm
- Load cell : LUR-A-SA1(KYOWA)
- Weight of Box : 35kg
- Sampling rate of data recording : 100 ms

The experiment material was selected synthetic fiber and cotton ropes because it is often used securing of the cargo. **Fig.2(a~b)** shows the composition of experimental apparatus, securing box and outline of motion simulator. It can be seen from the **Fig. 2(a)** that set up a cargo box for experiment on the ship motion simulator. The box was fixed to the bottom with turnbuckle, ring, load cell and rope. An initial tension of rope set up respectively according to experimental conditions.

Simulator operates by condition set in the control room and experiment data was recorded at time series. This ship motion simulator can be set up to maximum of range with roll $\pm 15^{\circ}$, pitch $\pm 20^{\circ}$ and heave 750mm



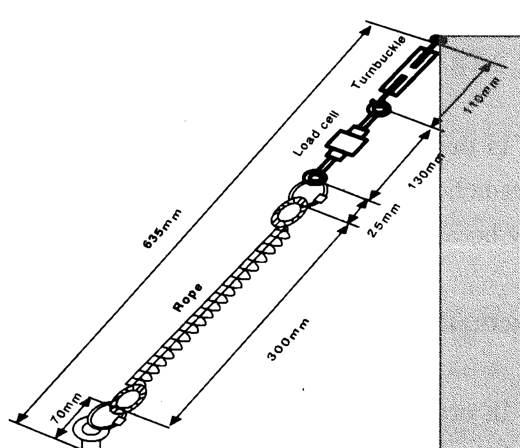


Fig. 2 (a) Composition of experimental apparatus

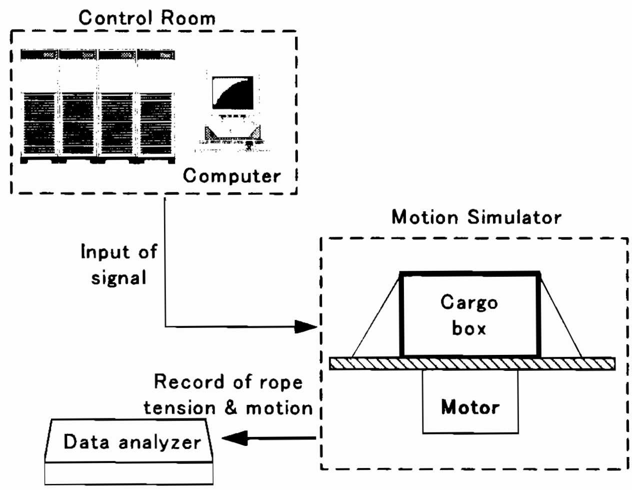


Fig. 2 (b) Outline of experimental apparatus

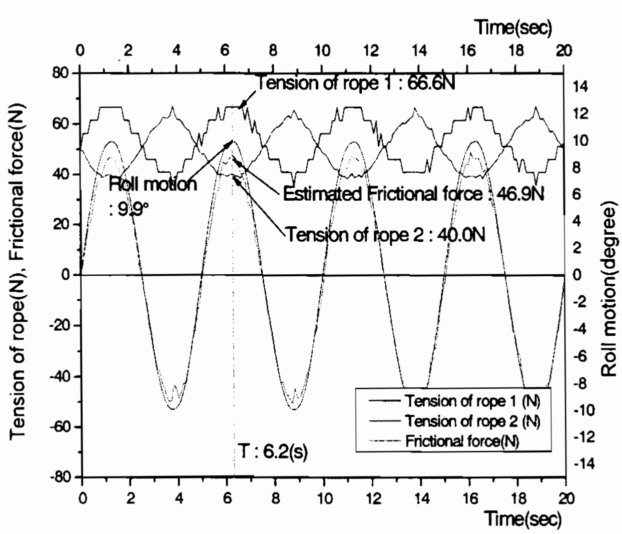


Fig. 3 Frictional force, tension by roll motion (Vinylon, ϕ =9mm, f=0.2Hz)

3.2 Result of experiment

3.2.1 Frictional force by roll motion

Fig.3 shows a sample of the result of the rope tension measured by experiment in case of following conditions.

- Type of rope : Vinylon ϕ 9mm
- Frequency : 0.2Hz
- Angle of roll : $\pm 10^\circ$

- Initial tension of rope : 5.0 × 9.8(N)

The horizontal axis is time (sec) and the vertical axis is the tension of load cell (1, 2), roll angle and the estimated frictional force. The figure shows that the rope tension and frictional force is changed according to roll motion. Estimated frictional force was calculated by the frictional force formula as shown in equation (4). For example, in case of the tension of rope 1, 2 and roll angle of any elapsed time(6.2sec) is 66.6N, 40.0N and 9.9 degree, the estimated frictional force was 46.9N as a result of calculation by formula(4).

3.2.2 Inclined angle and frictional force

Fig.4(a) was drawn by using **Fig.3**. The horizontal axis is inclined angle and vertical axis is the frictional force and frictional force is absolute value.

Look at the **Fig.4(a)**, frictional force have a tendency to straight line and can be obtainable a inclination of between roll angle and frictional force.

We carry out the similar experiments while changing a frequency, initial tension of rope, type of rope and rolling angle. As the results of experiment (example **Fig.4(b)**), inclined angle and frictional force had a tendency to straight line as like **Fig.4(a)**.

3.2.3 Approximate curve

We can derive a slope of vinylon 9mm rope from the inclined angle and frictional force (Fig.4) and the value of a slope is as follows(in this case initial tension of rope is 5.0 × 9.8(N)).

- f = 0.1Hz : 5.3
- f = 0.2Hz : 4.8
- f = 0.3Hz : 3.9

When the inclination of motion simulator was adjusted to 5 and 10 degrees, estimated

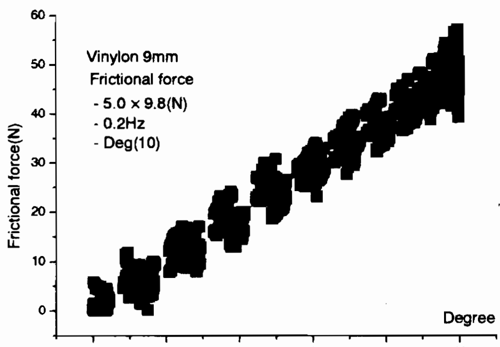


Fig. 4 (a) Comparison to the inclined angle and frictional force(Vinylon, ϕ =9mm, f=0.2Hz)

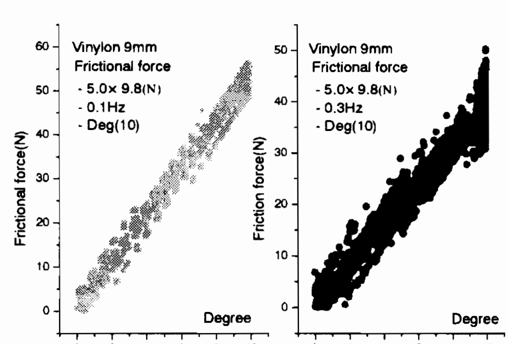


Fig. 4 (b) Comparison to the inclined angle and frictional force(Vinylon, ϕ =9mm, f =0.1, 0.3Hz) frictional force was calculated by the frictional force formula (4). The value obtained here is defined as the inclination when the frequency is 0 and the value becomes 5.7 for the vinylon 9 mm rope, initial tension 5.0 × 9.8(N).

Also, the result was added to **Fig.5** by using the same method when an initial tension is 2.5, 10.0 × 9.8N.

Fig.5 shows an approximate curve in the case of initial tension of vinylon 9mm rope is 2.5, 5.0, 10.0 × 9.8(N). The horizontal axis is the frequency of simulator and vertical axis is the value of frictional force/inclined angle.

The value of vertical axis is depended on initial tension of the securing rope and frequency of rolling. Increasing of frequency, vertical axis value is on the decrease.

3.2.4 Prediction of fluctuation tension

Using the **Fig.5** data, we try to prediction of fluctuation tension frequency on which it doesn't experiment. Firstly, we calculated fluctuation tension by formula(5) in case that no change of initial tension as initial tension is 2.5, 5.0, 10.0 × 9.8(N) respectively. But, just only changed frequency of ship motion simulator as 0.05, 0.15, 0.25 Hz. For example, in case of the frequency is 0.05Hz, initial tension is 2.5 × 9.8(N), the frictional force/degree of initial tension 2.5 × 9.8(N) is taken a proportional expression between 0Hz and 1Hz. The value becomes to 5.5 and substitutes it for frictional force (F_3) in formula (5). As a result, the prediction value of fluctuation tension is 29.0N by the calculation.

Next, we carried out the experiment on the same condition (initial tension 2.5 × 9.8(N) and frequency of ship motion simulator 0.05Hz). As a result, the experiment value of fluctuation tension is 32.4N.

On the same way, calculate the fluctuation tension in case of the frequency is 0.15, 0.25

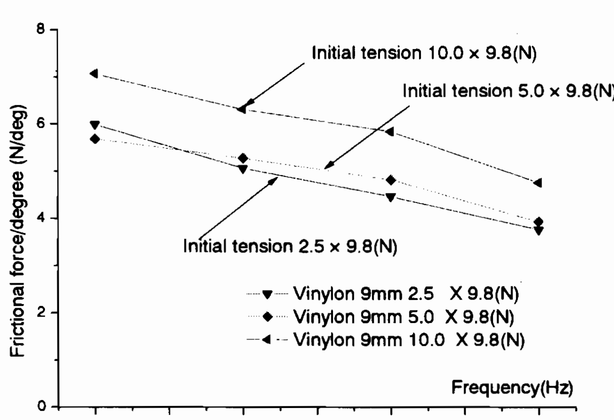


Fig. 5 Comparison between frictional force/ degree and frequency(Vinylon, ϕ =9mm)

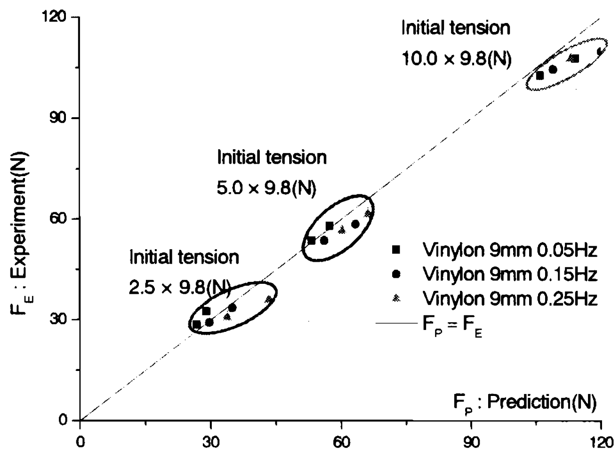


Fig. 6 Comparison of Prediction and Experiment

Hz, too.

Fig.6 shows the result of the comparison between the prediction by means of calculation and the experiment as results through the simulator. The prediction is almost corresponded to the experimental one.

As a result of **Fig.6**, we verified that it is possible to predict of fluctuation tension of frequency on which it doesn't experiment by using obtain the data through experiment.

If so, can predict of fluctuation tension in such a case of any initial tension and frequency? (For example, in case of initial tension is 3.5, 7.5 × 9.8(N) and frequency is 0.05, 0.15, 0.25Hz)

The frictional force is necessary to predict of fluctuation tension. So, the frictional force/degree of initial force 3.5 × 9.8(N) is taken a between the initial tension 2.5 × 9.8(N) and 5.0 × 9.8(N) in case of the 0.05, 0.15, 0.25Hz.

At the same time, the frictional force/degree of initial force 7.5 × 9.8(N) is the middle value of the initial tension 5.0 × 9.8(N) and 10.0 × 9.8(N) as 0.05, 0.15, 0.25Hz respectively. This frictional force/degree of initial force was substituted for the mathematical formula and calculated. Of course, the experiment was enforced according to the same condition above. **Table 1** shows the comparison of prediction and the experimental result. A percentage of accuracy to the gap between prediction and experimental result is defined as PE_P (%).

$$PE_P\,(\%) = \frac{(\text{prediction} - \text{Experiment})}{\text{Experiment}} \times 100$$

Table 1 Percentage of accuracy to the gap between prediction and experiment

Frequency (Hz)	Amplitude of oscillation (deg)	Initial tension (×9.8(N))	$\frac{\text{(Prediction - Experiment)}}{\text{Experiment}} \times 100(\%)$ Type of rope and diameter: Vinylon 12mm	Vinylon 9mm	Vinylon 6mm	Cotton 9mm
0.05	5	3.5	-3.8	-0.5	0.5	-1.8
		7.5	-6.8	-1.1	1.8	-1.1
	10	3.5	2.8	6.2	3.8	5.6
		7.5	3.8	2.8	5.1	1.7
0.15	5	3.5	-4.7	1.4	-2.5	4.2
		7.5	-2.1	6.4	9.5	6.6
	10	3.5	2.7	5.4	0.1	4.0
		7.5	3.8	3.6	4.4	8.5
0.25	5	3.5	5.0	3.3	7.1	4.4
		7.5	4.2	4.0	4.9	11.7
	10	3.5	4.0	3.9	3.8	3.6
		7.5	4.3	6.8	5.3	4.8

It can be seen from **Table 1**. PE_P (%)that the prediction and experiment is almost corresponding in such a case of any initial tension and frequency

4. Conclusion

In this paper, we carried out for prediction of fluctuation tension of the force to act on cargo securing rope by motion. In the experiment, we thought the case with only roll motion.

From the analysis above, we conclude the following:

1) We made a numerical formula with a balance of the forces of vertical and horizontal to act on the object. As a result of experiment, we confirmed that extend of the changing a frictional force and tension of rope according to change a frequency of simulator and type of rope.
2) Displayed to the approximation straight line through compare of the relations between the inclined angle and friction force. At the same time, we know that the frictional force/angle of roll is depended on initial tension and the frequency of the rope. We predicted the fluctuation tension in case of the arbitrary frequency and initial tension using data obtained through the experiment. The prediction was verified by experiment. It almost corresponded to the experimental one.

3) It can be predicted the fluctuation tension of the rope in case of arbitrary initial tension and frequency

If experiments on various conditions and the database are made, it will be possible to prediction of fluctuation tension by the motion. In addition to, it is useful to choose a suitable type of lashing rope and initial tension of rope at the securing.

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動揺による固縛索変動張力の予測

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船体動揺時の貨物移動防止のため、貨物の索による確実な固縛は、安全輸送品質保証のための重要項目であるものの、動揺によって固縛索に多数回の繰り返し張力が働くことで、索の永久ひずみが進行し、貨物移動事故の原因となることがある。貨物移動事故を未然に防ぐためには、固縛索の常時監視と増し締め作業が必要であるが、その運用は現場作業者の経験に依存しているのが実状である。
本研究は、動揺床上に固定された物体の固縛索の変動張力を予測することを目的として、船舶動揺シミュレータを用いた索張力計測実験を行った。索変動張力の結果をもとに、動揺の周波数・索初期張力と、物体と床面間の摩擦力・動揺振幅の関係を計算によって求めた。その関係を使うことによって、任意の索初期張力と動揺周波数での索変動張力を予測することが可能であり、固縛索選定や増し締め運用基準づくりのための基礎資料とすることができる。

キーワード：固縛、変動張力、動揺