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Prediction of Residual Tension of Securing Rope by Oscillation Test

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Abstract : *A lot of cargo accidents occurred due to insufficient securing in the case of marine transportation. If the residual tension of securing rope can be predicted, it will be very useful in the handling of cargo securing work of operators. It was confirmed in the previous study that the fluctuation tension of securing rope by oscillation could be predicted. In this paper, in order to the prediction of residual tension of securing rope, the experiments were carried out to measure the residual tension of securing rope under the oscillation and cyclic loadings. The residual tensions of two tests were in good agreement with each other. It can be predicted through the cyclic loading test in the estimated fluctuation tension without oscillation test by ship motion simulator.*

Key words : *Cargo Securing, Oscillation, Securing Rope, Residual Tension, Fluctuation Tension*

1. Introduction

Although the safety of cargo transportation is a wish of all the related people, there still remain various safety limitation elements. The durability of freight and packaging technology has been improved by the technical development, but the cargo accidents often occur by the carelessness treatments, unexpected danger elements, and so on. Since it usually takes a long time in the case of marine transportation compared to the other transportation ones, especially, a lot of risks could be followed upon its long navigation time. For the safe transportation, therefore, the operators usually decide the cargo handling methods, such as securing rope, lashing method, cargo arrangement, and so on, based on the securing manual or their practical experiences. However, a lot of cargo accidents still occur due to insufficient securing.

Cyclic loading usually makes securing rope oscillate under the navigation. Whereas the level of external forces at sea can be predicted through the analysis, the safety of cargo securing on board can not be judged easily because of unknown tension of securing rope. Quantitative evaluation method is needed for the evaluation of the securing safety of cargo before the departure or arrival at the destination.
As some works pointed out the failure strength of rope under the cyclic loading(1-5), its failure strength is usually much smaller than that under the tension loading. The repeated loading of securing rope is very diverse depending on the applied external forces, and rope tension of securing cargo is also greatly various according to the operational frequency, volume and level of external forces. Since the tension of securing rope could hardly be predicted quantitatively in the transportation, the cargo accidents occurred due to the improper securing of cargo. If the residual tension and fluctuation tension of securing rope can be estimated exactly during transportation, the cargo accidents will not happen by the insufficient securing.

It was confirmed that the fluctuation tension of securing rope under oscillation could be predicted analytically for the estimation of its residual tension by the authors(6). In this study, the experiments were carried out to measure the residual tensions of securing rope under the oscillation and cyclic loadings, and their residual tensions were compared with each other.

2. Experiments

2.1 Oscillation test

Fig. 1 shows a configuration of experimental apparatus, ship motion simulator, composed of steel box secured by rope and turnbuckle with load cell(KYOWA-LUR-A-SA1). The positive inclined angle of rolling motion is defined to the right side, as shown in Fig. 1. Test conditions, such as temperature and humidity, etc. were recorded periodically, which are as following.

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- Frequency of motion simulator (roll) : 0.3Hz
- Initial rope tension : 49N
- Inclined angle of rolling : ± 10 °
- Sampling rate of data recording : 100Hz
- Type and Diameter of rope : Cotton, ϕ 3mm
- Recording duration and interval time : 1 and 5 minutes
- Temperature and Relative humidity : 24~28℃, 58~65(%)

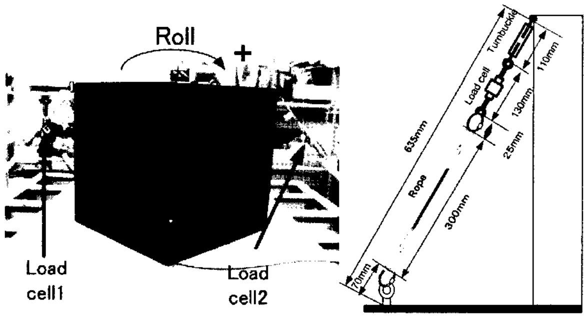


Fig. 1 Configuration of motion simulator

Fig. 2(a) illustrates an example of the rope tension responses according to the above experimental condition. The vertical axis represents both rope tension(N) from load cell 1 and 2 and roll motion(degree) according to time(sec). It can be seen from Fig. 2(a) that the rope tension is changed according to the roll motions and especially is fluctuated with high frequency at inclined angle change. Fig. 2(b) and (c) show its low-pass and high-pass filtering results using the 2nd order Bessel filter, respectively. Figure 2(d) shows low-pass filtering result between the elapsed time 23h 59m25s ~ 23h59m35s and dot line of residual tension(25N). The residual rope tension was obtained by the arithmetical mean of recorded data for 1 minute using low-pass filtering.

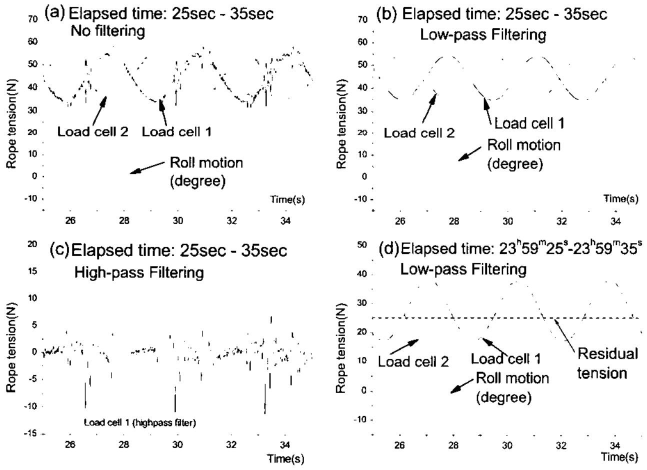


Fig. 2 Rope tension responses according to rolling motion

Fig. 3 shows the rope tension responses under rolling and natural conditions, where the symbol □ illustrates the residual rope tension under rolling condition, and the symbol △, under natural condition without consideration of the rolling condition in the laboratory(normal temperature). The rope tension became 39N at natural condition from the initial tension 49N, but it dropped to 25N after 24 hours under rolling condition. The securing rope tension was decreased naturally without any external factors. It could be found, however, that the residual tension of securing rope would be decreased much more under the rolling motion.

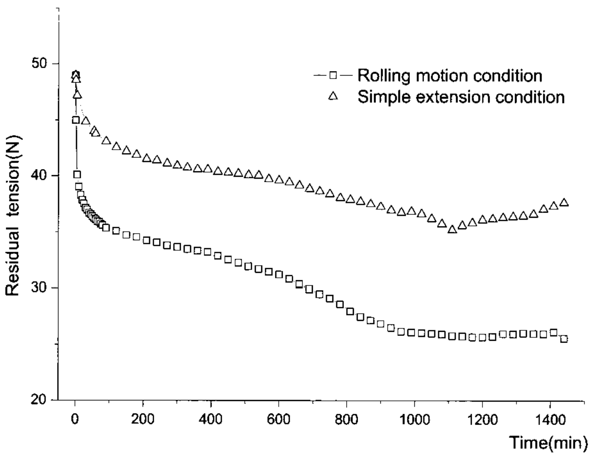


Fig. 3 Rope tension responses under rolling and natural conditions

Since the fluctuation tension of securing rope exists mixed with the component of low frequency and high frequency under oscillation test, as shown in Fig. 2(a)-(c), the vibration test of rope with natural high frequency is needed to be carried out for the verification of high frequency components in the residual rope tension.

2.2 Vibration test

Fig. 4 shows the configuration of vibration simulator with steel box fixed on the vibration table using the turnbuckle, shackle, load cell and rope. Sinusoidal vibration tests were carried out based on JIS Z 0232(7). The conditions of vibration test are as following.

- Sweep vibration range : 5 ~ 50Hz
- Reciprocating sweep time : 420, 600, 900, 1800(s)
- Count of reciprocating sweep : 1 time
- Vibration acceleration : 0.1g
- Initial rope tension : 49N
- Sampling rate of data recording : 100Hz
- Type and Diameter of rope : Cotton, ϕ 3mm
- Direction of vibrating : Vertical

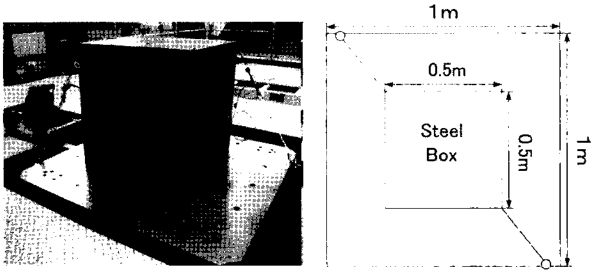


Fig. 4 Configuration of vibration simulator

Fig. 5 illustrates a process of sinusoidal sweep test to check the resonance frequency and the change of rope tension. The first step is to select the vibration acceleration, frequency of vibration simulator and to set up the initial tension of securing rope. The second one, to select the sweep vibration range and reciprocating sweep time for the search of resonance frequency, and the final one, to perform the measurement and analysis of rope tension by reciprocating sweep test.

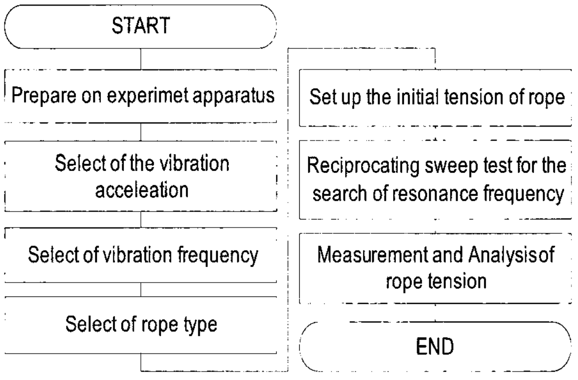


Fig. 5 Flow chart of vibration test

Fig. 6 shows the spectral charts of vibrating tension in the several reciprocating sweep times. The vertical axis represents the PSD(Power Spectrum Density, N^2/Hz) according to frequency(Hz). It could be found that there was not much difference in the resonance frequency with around 20Hz in the case of initial tension 49N, although it demonstrated diverse ranges of reciprocation sweep time.

The amplitude of rope tension might be the largest at the resonant frequency, that is, the rope tension change at the high frequency by the oscillation test, as shown in Fig. 2(c), could be smaller than that at the resonance frequency by the vibrating. Therefore, the vibration test of securing rope tension was carried out at the resonant frequency as following condition.

- Vibration frequency : 20Hz
- Sampling rate of recording time : 100Hz
- Recording duration and interval time : 1 and 5 minutes

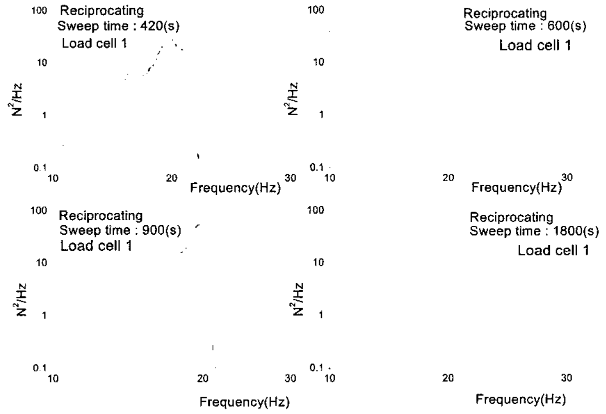


Fig. 6 PSD chart of vibration tension in the sweep tests

Fig. 7 shows the time history of the rope tension at the resonant frequency. The amplitude of rope tension did not change in each case of (a) elapsed time 10-11sec and (b) elapsed time 23^h59^m10-11sec, which was similar to the maximum amplitude of rope tension at the high frequency as shown in Fig. 2(c). Figure 8 illustrates the rope tension response under rolling, vibrating and natural conditions. The rope tension was calculated by the arithmetical mean of recording data for 1 minute(number of data : 6000).

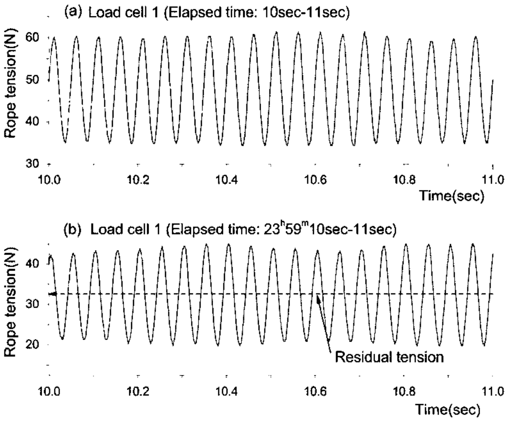


Fig. 7 Time history of rope tension at resonant frequency

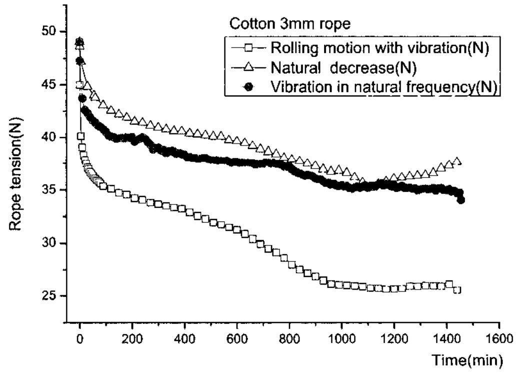


Fig. 8 Rope tension responses under rolling, vibrating and natural conditions

The symbol ● illustrates a mean change of the rope tension(load cell 1, 2) by the vibration in natural frequency, and the symbols, □ and △, are the same ones, as shown in Fig. 3. In case of the vibration in natural frequency, the initial rope tension was also decreasing gradually and became around 33N after 24 hours. However, there was not much difference between the rope tensions by the vibration in natural frequency and at natural condition without consideration of the rolling condition. It could be thought from this result that the cyclic loading with low frequency rolling motion has the greatest influence on the rope tension.

2.3 Synchronized oscillation test

While the relationship between the fluctuation rope tension and residual one by rolling motion was compared in the previous section, the experiment was carried out for the rope tension behavior according to synchronized motion with heave one in this section. The experiment conditions are summarized in Table 1.

Table 1 Experiment condition with synchronized motion

Frequency(Hz)		Roll Angle Heave Amplitude		Initial Phase Difference
Roll	0.25	Angle	± 5·10°	$0, \frac{\pi}{2}, \pi, \frac{3\pi}{2}$
Heave	0.1, 0.2, 0.3, 0.4, 0.5	Amplitude	20cm	
Roll	0.25	Angle	± 5·10°	
Heave	0.1, 0.2, 0.3	Amplitude	10cm	

Fig. 9 shows the average fluctuation of rope tension according to heave frequency in the case of heave amplitude 20cm and roll frequency 0.25Hz with roll angle 10°. The fluctuation tension shows little change makes a comparison between only roll motion and synchronizes with heave motion. Also, the range of fluctuation tension by phase difference is appeared lower on the whole in comparison with only roll motion.

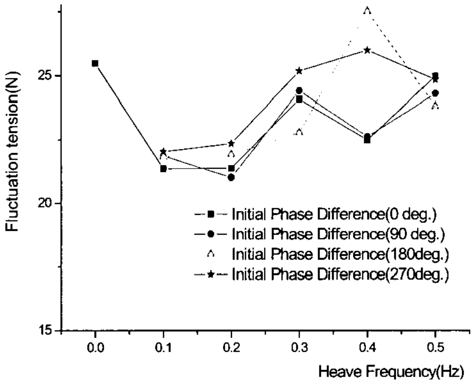


Fig. 9 Comparison of fluctuation tensions according to phase angle

3. Residual tension

3.1 Cyclic loading test

In the case of initial tension 49N, the amplitude of the cyclic rope tension was measured about 30~60N during the beginning 1 minute by the ship motion simulator. But, the rope tension was decreased by the repeated motion and its range became 15~35N after about 24 hours, as shown in Fig. 2(d). Thus, it could be confirmed that the residual tension of securing rope decreased by the cyclic loading under transportation.

If the residual tension of rope can be predicted, the cargo securing work of operators will be proper and useful. In the previous chapter, it was confirmed that the residual tension of securing rope by cyclic loading could be predicted. But, There are many cases that cannot use such an experiment. Therefore, to verify the effectiveness of predicting of residual tension by the examination using the cyclic loading tester, carried out the cyclic load test. The experimental condition is as following and in Table 2.

- Type and Diameter of rope : Cotton, ϕ 3mm
- Loa of rope : 270mm
- A number of cyclic load : 1000times
- Sampling rate of data recording : 20㎳
- Initial tension of rope : 49N
- Temperature and Relative Humidity : 25℃, 60%
- Frequency of cyclic load test : 0.26Hz

Table 2 The general specification for cycle load test

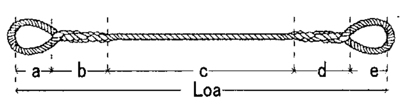
Items		Specification					
Software of data processing		A-AND-D MAST02~04V2 for cycle test					
Load tester		A-AND-D STA1225					
	Type	a	b	c	d	e	Loa
	I	30	40	125	45	30	270
	II	30	38	132	40	30	270
Rope(mm) -Cotton ϕ 3mm		 unit:(mm)					

Fig. 10 shows a configuration of the cyclic loading test. The extension length of the rope was measured 25.3mm at 30N, and 26.8mm at 60N. Two loads, 30N and 60N, were the bound pairs of the range of rope tensions by the rolling motion, as shown in Fig. 2(a). Therefore, the cyclic loading was set between two displacement amplitudes, 25.3 and

26.8mm, at the cyclic loading tester.

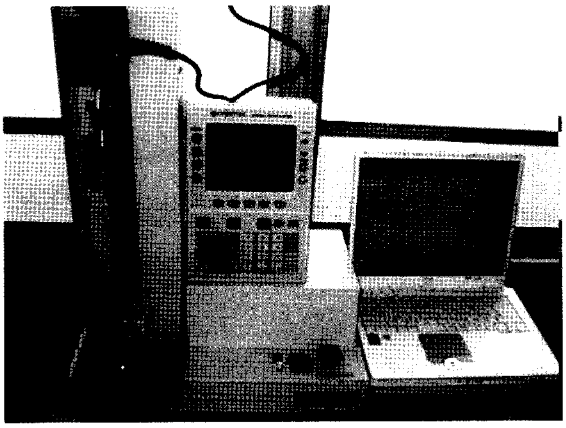


Fig. 10 Configuration of cyclic loading tester

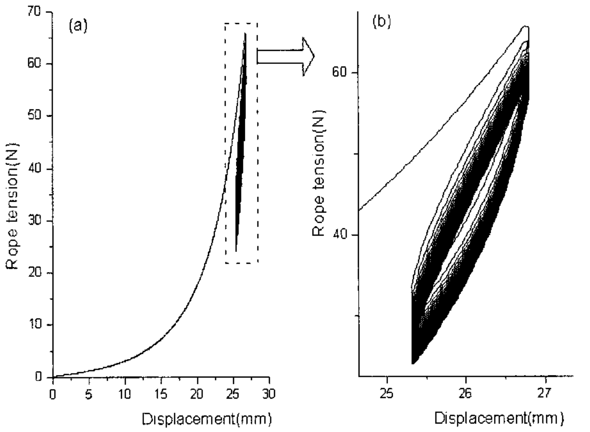


Fig. 11 Cyclic rope tension response of cotton rope type-Ⅱ

Fig. 11 shows a result of type-Ⅱ rope tension under the cyclic loading. The cyclic rope tension was decreased little by little under the cyclic range of displacement amplitudes, and the total rope length(Loa) became 283mm after 1,000 time cyclic loading.

3.2 Comparison of residual tension between the oscillation test and the cyclic loading test

Fig. 12 shows the schematic diagram of calculation method for the residual rope tension under the cyclic loading test. The residual rope tension, RT(n), at cyclic loading times n was defined as the following Eq. (1), as shown in Fig. 12,

$$RT(n) = \left(\frac{F(n) + f(n)}{2}\right) \tag{1}$$

where, $F(n)$ and $f(n)$ are the maximum and minimum rope tension at the mean displacement amplitude 26.05mm of cyclic loading times n.

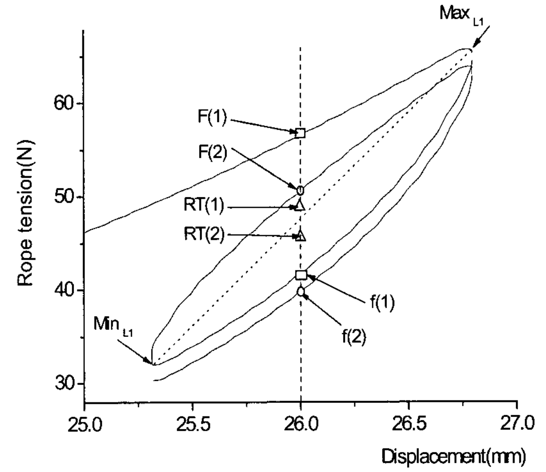


Fig. 12 Schematic diagram of residual cyclic rope tension

The spring constant $k_{rope}(N/mm)$ was defined as the following Eq. (2) and the average of spring constant became $24.74(N/mm)$,

$$k_{rope}(N/mm) = \frac{Max_{L(n)} - Min_{L(n)}}{Max_{D(n)} - Min_{D(n)}} \tag{2}$$

Where, $Max_{L(n)}(N)$ and $Min_{L(n)}(N)$ are the maximum and minimum loads, and $Max_{D(n)}(mm)$ and $Min_{D(n)}(mm)$, the maximum and minimum displacement at the cyclic loading times, respectively.

Fig. 13 shows the comparison of the residual rope tensions between the oscillation and cyclic loading tests, where time history of residual rope tension of the rolling motion in Fig. 8 was converted into that according to cyclic count. Their residual rope tensions are also summarized in Table 3 with the percentage of accuracy CR(%) as defined in Eq. (3). As shown in Fig. 13 and Table 3, it could be found that these two residual rope tensions were in good agreement with each other.

$$CR(\%) = \frac{Cycle\ loading\ test - Oscillation\ test}{Oscillation\ test} \times 100 \tag{3}$$

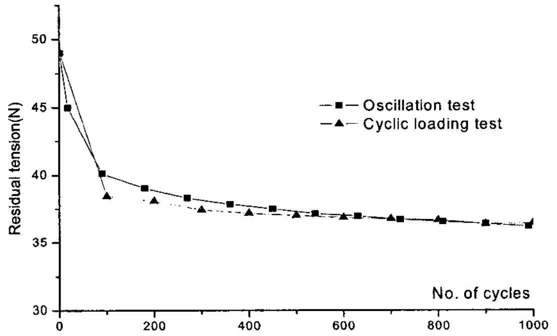


Fig. 13 Comparison of residual rope tension between oscillation test and cyclic loading test

Table 3 Comparison with the two tests

No. of cycles	Residual rope tension(N)		CR(%)
	Oscillation test	Cyclic loading test	
1	49	49.09	0.19
18	44.98	40.67	-9.58
90	40.11	38.58	-3.82
180	39.034	38.32	-1.85
270	38.314	37.74	-1.48
360	37.854	37.59	-0.69
450	37.51	37.54	0.067
540	37.14	37.01	-0.35
630	36.964	36.85	-0.31
720	36.72	36.76	0.11
810	36.56	36.66	0.27
900	36.39	36.39	-0.02
990	36.21	36.52	0.86

4. Conclusion

In this paper, the experiment and analysis for prediction of residual tension of the rope were carried out under the cyclic loading during transportation. The following results were obtained as the conclusion.

(1) The cyclic loading with low frequency rolling motion has the greatest influence with rope tension.

(2) The fluctuation tension was little change makes a comparison between only roll motion and synchronizes with heave motion.

(3) The fluctuation tension of securing rope exists mixed with the component of low frequency and high frequency nuder oscillation test.

(4) The cyclic load test was carried out to verify the effectiveness of prediction of residual tension using the cyclic loading tester.

(5) The residual tension of securing rope can be predicted through the cyclic loading test in the estimated fluctuation tension.

In additionally, it need to evaluating a safety degree of securing rope through the prediction of residual tension.

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