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A Quantitative Assessment on a Tension of Securing Rope to evade Marine Accidents caused by Improper Cargo-Securing

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Abstract : *To prevent cargo accidents by repeated loads, a continuous monitoring for securing rope or additional safety measures are needed, but most of prevention measures have been conducted only by operator's own experience not a quantitative assessment. Hence, the Load-Displacement curve and approximation formula of securing rope were drawn in this research for a quantitative assessment and simplified measurement on a tension of securing rope using a tensiometer. Moreover, a comparison was conducted between measuring tension and calculated tension on securing rope with portable tensiometer, 'Load-Displacement' approximation formula. The calculated tension of securing rope is obtained 153.3kfg using the formula and that result has not much difference with initial tension 150.0kgf. Lastly, an analysis of the characteristics of various ropes was suggested to enhance the reliability about quantitative assessment of securing rope's tension through further research.*

Key Words : *Cargo securing, Ship motions, Load-Displacement curve, Cargo Accident, Quantitative assessment*

1. Introduction

The operators usually decide the cargo handling methods based on the manual and their practical experience, such as a selection of securing devices, lashing method, cargo arrangement, and so on.

However, the securing rope tensions are checked according to the personal experience at the process of securing works, because of the set up and checking a securing rope tension is not prescribed, and there is a personal difference on a judgement.

Moreover, it's not easy to judge the safety of cargo securing status because of the unknown tension of securing rope. A repeated loading of securing rope is very diverse depending on the applied external forces, and rope tension of securing cargo is also greatly various depend on the operational frequency volume and level of external effects. In case of the marine transportation, especially, the definite securing is necessary for prevent of cargo accidents, such as damages, loss, movements and collapse of cargo by ship’s motion in sea-waves. Also, it is necessary to check the general condition and tension of securing rope periodically and required to securing of sufficient and proper for it.

The cargo securing system is to prevent the cargoes from topping, shifting, sliding tilting and exceeding the permissible forces under the transportation. For the safety transportation, therefore, the securing devices should be always monitored and checked by the operators, because of the cyclic loading acts on the securing rope by the ship motions and a permanent stretch of the rope will be possible to cause the cargo accidents. If necessary, it will be replaced with a new one in the bad condition. Nevertheless, it is not to easy a checking and monitoring condition of securing devices and tension of lashing rope during the transportation; in actual, it is impossible to monitor continuously.

Since the tension of securing rope could hardly be predicted quantitatively during the transportation, a lot of cargo accidents occurred due to the improper and insufficient securing. In other words, if the residual tension and fluctuation tension of securing rope can be estimated exactly during transportation, the cargo accidents will be reduced or not happened by the reason of above. Therefore, it is necessary to set the optimum tension of the securing rope based on the quantitative evaluation for the securing works of cargo before the departure or after arrived at the destination as shown in Fig. 1.

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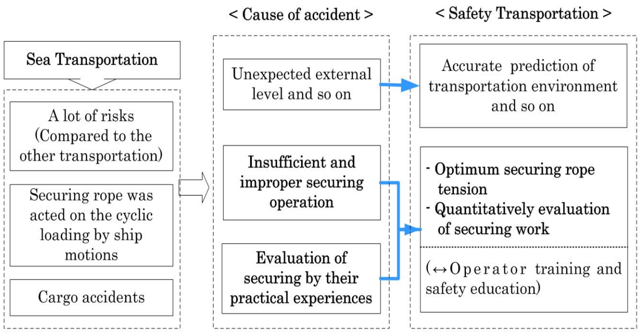


Fig. 1. Considerations for safety transportation(Cargo handling and securing).

After effectuation of the code of safe practice for cargo stowage and securing from IMO(IMO, 1997; 2003), a number of studies about cargo stowing and securing were conducted by each classification society(Lloyd`s Register, 2005) and related organizations.

However, most researches were confined to the subjects of lashing loads of containers(Yoon et al., 2005), securing system (Shin, 2003) and efficient cargo stowage(Nakamura et al., 2000). There is no specific research about a way to evaluate the tension of securing rope by on-site worker.

Firstly, author have proved the possibility of fluctuation tension prediction from ship oscillation and residual tension prediction from the repeated load, through ship motion simulator test in author's precedent research, also suggested safety assessment tool for tension of securing rope(Kim and Saito, 2007; 2008a; 2008b).

In this research, the test about prediction of securing rope's tension was carried out and the test result was presented to implement a quantitative assessment about cargo lashing work for safe marine transportation.

2. Status of Marine Transportation

2.1 Analysis of Marine transportation accidents

As shown in Fig. 2, the cargo is under the stress like as vibration, oscillation, compression and so on; So, it needed an appropriate packaging, carelessness treatments and sufficient securing for safety transportation. To elevate the efficiency and safety of transportation, the cargoes are unitized by the pallet and/or the container.

The durability of freight and packaging technology has been improved by the technical development, but the cargo accidents are still occurred by the carelessness treatments, unexpected danger elements and so on.

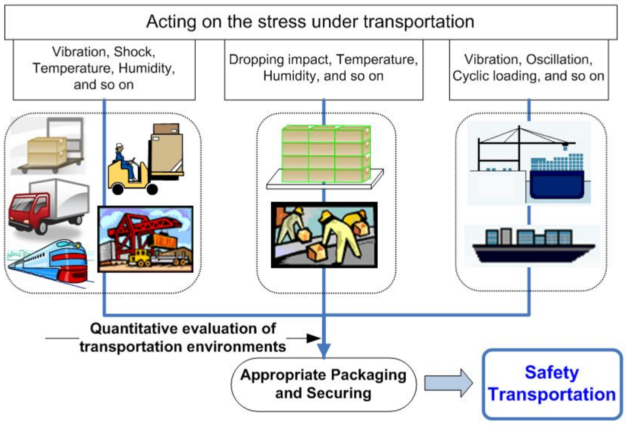


Fig. 2. Stress and safety under transportation.

For the analysis of marine transportation accidents, the NKKK(Nippon Kaiji Kentei Kyokai, 2015)'s actual statistic data about imported marine cargo accidents during 2 years (2011. 4. 1.~ 2012. 3. 31.) quoted in here and categorized 6,300 imported container cargo accidents as shown in Table 1.

Table 1. Statistic data of imported maine cargo accidents

Kind of Damage	Y2011	Y2012	Total	
	No.	No.	No.	Ratio(%)
Breakdown, Strain	1146	897	2043	32.7
Fresh water inflow	537	508	1045	16.7
Stain	360	324	684	11.0
Freezing, Defrosting	210	372	582	9.3
Condensation	212	253	465	7.4
Salt water inflow	190	182	372	6.0
Discoloration, Spoilage	195	127	322	5.2
Contamination	53	109	162	2.6
Corrosion	117	0	117	1.9
Rusty	38	34	72	1.2
Etc.	175	207	382	6.1
Total	3233	3013	6246	100

In this paragraph, the cargo accidents in steel products, iron products (Coil, Copper plate, Stainless steel) were analyzed as like Table 2 and Table 3, 4 shows the cause and place of accidents.

About 70 % of accidents were occurred during transportation and about 50 % were caused by oscillation/Vibration, improper stowage/loading. Moreover, over 40 % of accidents were came from mishandling of cargo gear(Forklift, Crane and etc.) due to the characteristics of the container cargo operation. That shows the necessity of proper education or training for cargo gear operator.

Table 2. Categorization by places of damage

	Y2011	Y2012	Total	
	No.	No.	No.	Ratio(%)
Breakdown, Strain	72	67	139	51.3
Salt water inflow	20	19	39	14.4
Fresh water inflow	24	14	38	14.0
rusty	20	4	24	8.9
Condensation	5	8	13	4.8
Etc.	13	5	18	6.7
Total	154	117	271	100.0

Table 3. Categorization by places of accident

Place of Accident	Y2011	Y2012	Total	
	No.	No.	No.	Ratio(%)
During transportation	54	42	96	69.1
During vanning	12	13	25	18.0
During devanning	3	2	5	3.6
Etc.	3	10	13	9.4
Total	72	67	139	100.0

Table 4. Categorization by causes of accident

Cause of Accident	Y2011	Y2012	Total	
	No.	No.	No.	Ratio(%)
Mishandling of Equip.	27	34	61	43.9
Oscillation/Vibration during voyage	25	14	39	28.1
Bad weather	12	7	19	13.7
Improper loading	5	8	13	9.4
Improper Securing	0	1	1	0.7
Etc.	3	3	6	4.2
Total	72	67	139	100.0

2.2 Evaluation procedures for Safe Marine Transportation

Recently, a demand for marine transportation of heavy lift cargoes such as plant equipments, module and so on, have been increased. This causes the spatial distribution problem in cargo space, clash accident with other cargoes or ship structure due to the swaying of crane. In addition, some kind of machines and electronic devices are vulnerable to salt water intake. Hence, special measures are essential to protect a wet damage on cargo. Fig. 3 shows the evaluation work flow for safe transportation of cargo.

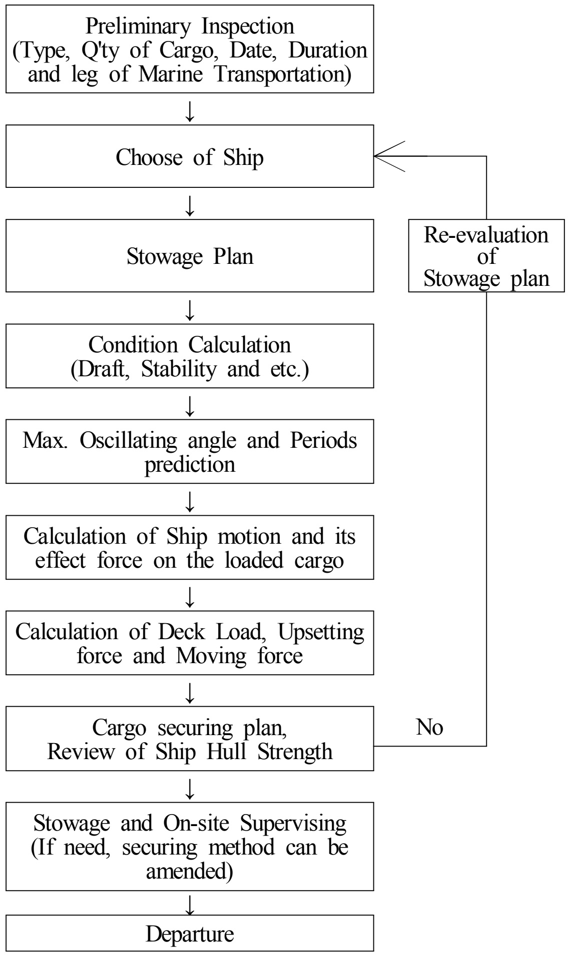


Fig. 3. Work flow for Safe Transportation of cargo.

On the other hand, when a cargo is transported by ship, the ship's maximum oscillating angle and its effects on the cargo should be considered. For this purpose, three components of force(acceleration); Fore and after, vertical, horizontal are gained and should be carried out a evaluation for endurance of cargo itself, deck load, securing measures and its strength.

Basically, onshore plant equipments are designed by land-based strength criteria without consideration of ship oscillation during marine transportation. So, it requires meticulous care.

If the extreme difference between ship's buoyancy distribution and load distribution are existed, not only a local strength of hull but total longitudinal strength are also reviewed. Moreover, a method of cargo handling work and workload of equipments should be considered for safety.

Especially, when check a strength of wire rope lashing, the most vulnerable wire rope which is made of the weakest material should be checked preferentially. Furthermore, when lashes one cargo with multiple ropes in the same direction, it contains possibility of wire cutting from most stretched rope due to the imbalance of tension. So, when the multiple lashing wires are used, each wire should have same tension with others.

Hence, if a quantitative assessment of tension through the measurement of tension on the working spot, it can be minimize the worries about cargo accident.

3. Simplified Measurement of securing rope tension

The securing works is conducted to prevent the movements and the collapse of cargo during the voyage, but the repeated loading acts on lashing rope and freights by unpredictable external forces. Because of this, the securing works shall be to appropriate and sufficient from the beginning.

About the securing rope tension, it will be occurred the personal differences because of worker's different skill or habit. But, the total of the securing tension values of the securing devices on each side of a unit of cargo(Port as well as Starboard) should be equal to the weight of the unit. Therefore, the securing works is necessary to do precisely through the quantitative evaluation of the securing rope tension.

3.1 A theory of prediction of securing rope tension

Fig. 4 shows the balance of tensile forces to predict the tension of securing rope(F) which has unknown intial tension(F_0) through a portable tensiometer.

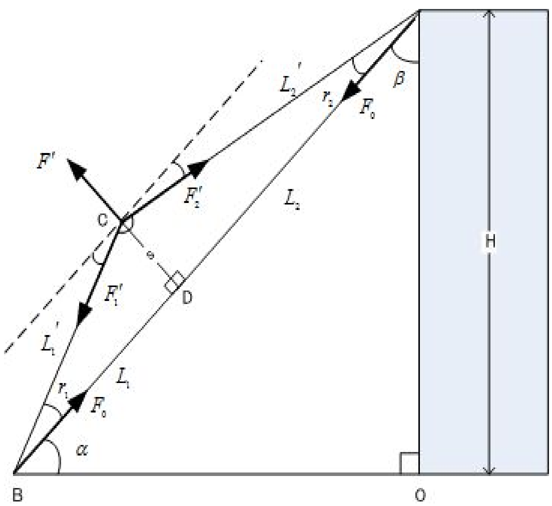


Fig. 4. Prediction of securing rope tension by tensiometer.

When pulled a certain part of securing rope(D) with certain distance(s), a tension of securing rope(F) is expressed as the formula (1).

$$F' = F_1' \sin r_1 + F_2' \sin r_2$$
$$= F\{(\ell_0 + \triangle\ell_1)\sin r_1 + (\ell_0 + \triangle\ell_2)\sin r_2\}$$
$$\therefore F = \frac{F'}{\{(\ell_0 + \triangle\ell_1)\sin r_1 + (\ell_0 + \triangle\ell_2)\sin r_2\}} \quad (1)$$

where,

F : Tension of securing rope(= Cal. Initial tension)

F' : Tensile Force, F_0 : Initial tension

3.2 Experimental Result

In this part, a comparison between the initial tension of securing rope and the calculated initial tension is carried out using the formula 1 and the testing equipment which consist of turnbuckle, rope and load-cell like as Fig. 5. In here, each Load cell presents the difference of initial tension on securing rope (Load-cell 2) and Tensile Force (Load-Cell 1).

Polypropylene(P.P) and Cotton rope were selected on this experiment and measured the Tensile Force(F') when pulled the rope in certain distance(10 cm). Table 5 shows the result of each rope and find the similarity between the initial tension(preset) and the calculated initial tension of each rope.

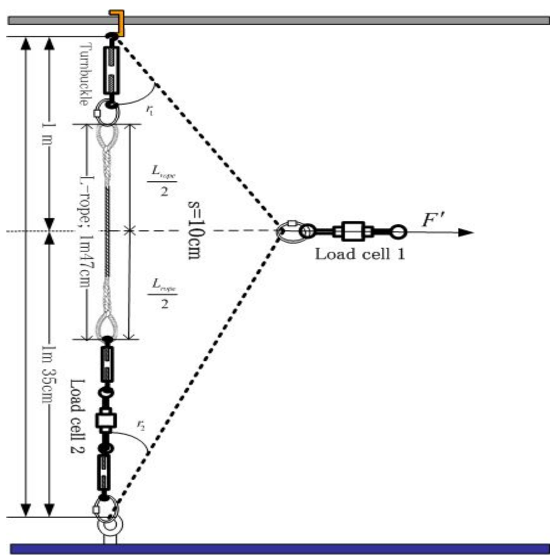


Fig. 5. Configuration of testing system.

Table 5. Comparison of test result on each rope

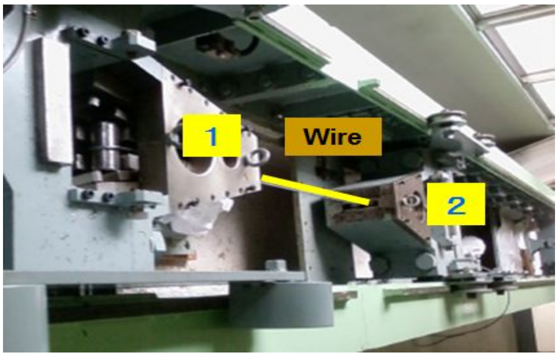
Item / Rope	Initial tension(N)	r_1 (deg.)	r_2 (deg.)	s(cm)	$F^{'}$	F (Cal. Initial tension, N)
P.P. 5 mm	30	8	5	10	17	31.90
	50	8	5	10	28	52.54
Cotton 3 mm	30	8	5	10	15	28.15
	50	8	5	10	26	48.80

3.3 Verification of practical applicability

To review the practical applicability of experimental result on paragraph 3.2, the additional experiment was conducted using wire rope which has been mainly used on workplace to secure a cargo.

Firstly, the Tensile Testing Machine in Fig. 6 was used to evaluate tensile properties of rope on Table 6. The 'Load-Displacement curve' is shown in Fig. 7, a red line indicates variation of tension power with different tensile forces and a green line shows the approx. formula which was derived from the curve.

(a) Rope Tensile Testing Machine



(b) Rope Tensile Test

Fig. 6. Rope Tensile Testing Machine.

Table 6. Specification of the rope

Diameter	Breaking Load	Type & Length	
14 mm	8.88 tf	6 × 24	1.5 m wire

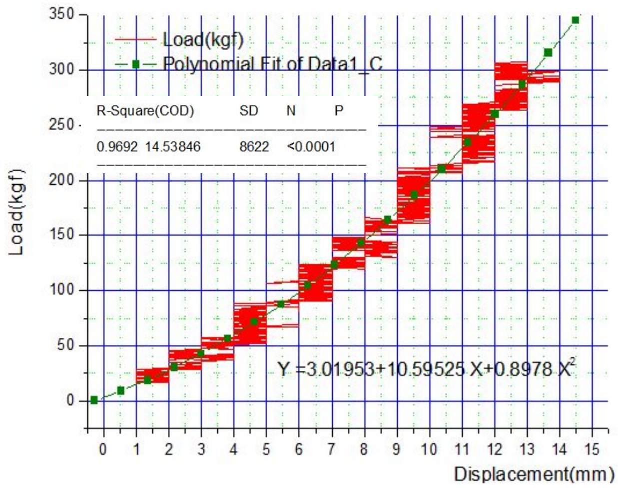


Fig. 7. Load-Displacement curve and approx. formula.

To know the tension on securing rope, measure the tension on portable tensiometer ($F^{'}$) after pull the rope in certain distance(s) in the same way with paragraph 3.2.

Then, the tension of moving rope(F_{after}) and changes of rope length($\triangle\ell$) are calculated by trigonometric function. Read the displacement which comes from calculated tension and move the x-axis point as the change of rope length($\triangle\ell$) and read the load in Y-axis. That point in Y-axis is the initial tension of securing rope. Fig. 8 shows the experimental results of pulling with certain distance (s = 2 cm) on the graph.

As stated before;

$$F_{after} = 161.3\ \text{kgf} \quad \text{and} \quad \triangle\ell = 0.00031\ \text{m}$$

were calculated by trigonometric function.

The calculated initial tension of securing rope is obtained 153.3 kgf using 'Load-Displacement' Graph and that result has not much difference with initial tension(150 kgf) as shown Table 7.

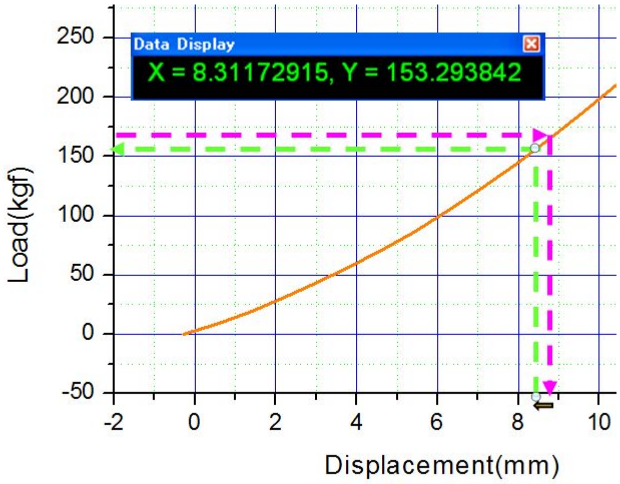


Fig. 8. Initial tension calculation by Load-Displacement curve.

Table 7. Comparison of result by experiment

s	F'	F_{after}	$\Delta\ell$	F_0	Calculation (Graph)
2 cm	5 kgf	161.3 kgf	0.00031 m	150.0 kgf	153.3 kgf
3.5 cm	10 kgf	185.8 kgf	0.000942 m	170.0 kgf	161.3 kgf

4. Conclusion

In the event of long-distance marine transportation, it is very difficult to move the cargo safer and to keep the cargo condition better than other transport modes(Airplane, Car, Train), because of a lot of external effects which came from ship's motions acted on the securing devices and packaged freight repeatedly. During the securing operation, therefore, the tension of securing rope should be evaluated in order to keep the safety and get economical efficiency.

In this research, simplified tension measurement was suggested. For that, the 'Load-Displacement' Curve and its approximation formula were derived from the tensiometer test.
Moreover, the comparisons were conducted between measuring tension and calculated tension on securing wire with portable tensiometer and 'Load-Displacement' approximation formula. This helps inspector or workers check the tension of securing rope handily.

For further research, an analysis of the characteristics of various ropes' load-displacement curve is recommended to enhance the reliability about quantitative assessment of securing rope's tension.

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