Study on Optimum Tension of Securing Rope

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(Degree)
博士（工学）
(Date of Degree)
2009-09-25
(Date of Publication)
2014-08-12
(Resource Type)
doctoral thesis
(Report Number)
甲4786
(URL)
https://hdl.handle.net/20.500.14094/D1004786

Doctoral Dissertation

Study on Optimum Tension of Securing Rope

(合理的な固縛索の張力設定に関する研究)

July, 2009

Graduate School of Science and Technology

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A Study on Optimum Tension of Securing Rope

ABSTRACT

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.

The cargoes are influenced on the external effects under the carrying, loading/unloading, transport and storage, 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.

From 1 January 1998, in accordance with the SOLAS (International Convention for the Safety of Life at Sea) 1974 Chapter VI, VII and the CSS (Code of Safe Practice for Cargo Stowage and Securing) code, Cargo Securing Manual was obliged on board to prevent of cargo accidents by the insufficient and improper securing.

However, a lot of cargo accidents still occur due to the inappropriate deck work or cargo work and defective stowage of cargo and so on.

The cargo securing operators usually decide the cargo handling methods based on the cargo securing manual and their practical experience. However, there is a personal difference on a judgment due to the securing rope tensions are checked according to the experiences.

According to the manual, the securing devices are selected based on the evaluation of external effects acting on cargo unit when subjected to the maximum acceleration.

But, it leaves much room for considerations, in case of the selection of the securing devices, because of those were acted on cyclic loading by the hull motions and a permanent stretch of the rope will be possible to causes the freight collapse and the movement accident.

Whereas the level of external forces at sea can be predicted through the statistic analysis, the safety of cargo securing on board can not be judged easily because of unknown tension of securing rope; the initial tension of the ropes by the securing work is adjusted by experience of the field worker's according to the questionnaire survey and field observation, and there becomes a difference by a person.

For the safe transportation, therefore, the securing operation is necessary to do certainly through the quantitative evaluation of securing rope tension.

2. Survey of the Field & Cargo Securing

The Cargo Securing Manual specifies arrangements and cargo securing devices provided on board the ship for the correct application to and the securing of cargo units, containers, vehicles and other entities, based on transverse, longitudinal and vertical forces which may arise during adverse weather and sea conditions.

However, According to MAIA (Marine Accident Inquiry Agency), about 170 cases of marine accident occurred last 4 years (2004 - 2007) due to the inappropriate deck work or cargo work, and defective stowage of cargo), and the number of cases was occurred about 3.3 percentage of the total accident cases.

To prevent cargo accident like above case, the securing operation should consider residual tension and fluctuation tension of securing rope by act on cyclic loading when assumption of external force by hull motions.

For the set an optimum tension of securing rope, it was surveyed in regard to the securing work and tension of securing rope through the observation of field and questionnaire.

3. Prediction of Fluctuation Tension of Securing Rope

For the prediction of fluctuation tension of securing rope by external force, the balance of forces action on the secured cargo by motion was calculated, and the basic experiments were carried out by the ship motion simulator.

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.

4. Prediction of Residual Tension of Securing Rope

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, and their residual tensions were compared with each other; because 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 and improper securing.

The cyclic loading test was carried out to verify the effectiveness of prediction of residual tension using the cyclic loading tester. As a result, the residual tension can be predicted through the cyclic loading test in the estimated fluctuation tension.

5. Optimum Initial Tension of Securing Rope

The concept of minimum safety tension and safety degree is introduced to evaluate of the safety of rope tension by predicted residual tension curve. So, it makes a proposal that the setting method an optimum tension of securing rope.

6. Conclusion

The main conclusions are summarized below.

(1) For the safe transportation, the cargo securing is necessary to do certainly by the quantitative evaluation.

(2) The experiment and analysis was carried out to prediction of fluctuation and residual tension of securing rope under the oscillation.

(3) The safety degree of the rope tension is evaluated by the residual tension curve.

(4) The concept of safety initial tension is introduced to setting method an optimum tension of securing rope.

If experiments on various conditions (for example, other material, transportation environment and so on) and the database are made, it will be possible to prediction of fluctuation tension and residual tension of securing devices by the motions.

Furthermore, it is necessary that when the settings of the minimum safety tension, the check of the transportation environment or the level of external forces, and the proposed method should be improved by checking on the residual tension in actual condition.

Additionally, it is more need research to set of optimum rope tension and to safety evaluation of the rope tension on the various conditions and structure of material, and the simply checking and measuring method of rope tension in the field.

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Chapter 1 Introduction

1.1 Prologue

Many modern people are possible to purchasing the goods to easily using the internet web site or at the near shopping centers. Those of materiality and immateriality are arrived to consumer through the process of physical distribution; packaging, loading/unloading, transport and storage.

In generally, the loading/discharging of packaged freights is mechanized through making to the pallet and containerization, and the unit loading system is operated in transportation and storing and so on. For that reason, it is necessary to appropriate packaging for prevent from damages and keep the value of goods to the external effects under transportation, for example, the vibration, impact, compression, temperature /humidity and so on.

The appropriate packaging of the freight was evaluated by test such a vibration, compression and dropping impact as possible to occur in the transport environments (1).

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, for example, the selection of the cushioning materials, the development of the packaging design and the durability improvement of products, and so on, but the cargo accidents often occur by the carelessness treatments, unexpected danger elements, and so on.

In case of the carrying of bulk cargo and overseas trade, the most of transport vehicles used is ship, because it is possible to bulk loading and has advantage of environmental that compared to other vehicles; ship emits less carbon dioxide, nitrogenous compound and other harmful pollutants and then again it is susceptible to the weather, most transportation is long-distance. 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.

1.2 Background

The cargoes are influenced on the external effects while the carrying, loading and transport of cargos. So, to keep the value of goods for the external forces in the transportation, it is needs not only an appropriate packaging technique, but also evaluation of securing operation.

IMO (International Maritime Organization) has published Guideline for the Preparation of the Cargo Securing Manual (CSM, 1997), the Code of Safe Practice for Cargo Stowage and Securing (CSS code, 2003) [2, 3, 4]. In these manual contains an arrangement or quantity of lashing device, method of securing and the result of evaluated stability of securing.

From 1 January 1998, in accordance with the SOLAS (International Convention for the Safety of Life at Sea) 1974 Chapter Ⅵ, Ⅶ and the CSS code was obliged cargo securing manual on board with the object of prevent cargo accident by the insufficient and improper securing for all ships. Based on these regulations, the marine company and classification society was drawn up a suitable cargo securing manual and guideline respectively [5 ~ 8].

Surprisingly, the important of securing is often noted but rarely study. The most of research was the optimum loading of stowage, the lashing method of securing rope and strength of container through the estimated force acted on securing and lashing system in waves [9 ~ 12].

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 work, because of the according to set up and checking a securing rope tension is not prescribed, and then there is a personal difference on a judgment.

Moreover, the safety of cargo securing on board can not be judged easily because of unknown tension of securing rope. 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 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 motion in sea-waves. Also, it is necessary to check the general condition and tension of securing rope by periods, 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. But, it is not to easy a checking and monitoring condition of securing devices and tension of lashing rope in transportation; in actual, it is impossible to monitor continuously.

Since the tension of securing rope could hardly be predicted quantitatively in the transportation, a lot of cargo accidents still occurred due to the improper and insufficient securing. The 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 happen by the reason of above.

Therefore, it is necessary that the set of the optimum tension of the securing rope based on the quantitative evaluation for the securing of cargo before the departure or after arrived at the destination as shown in Figure 1-1.

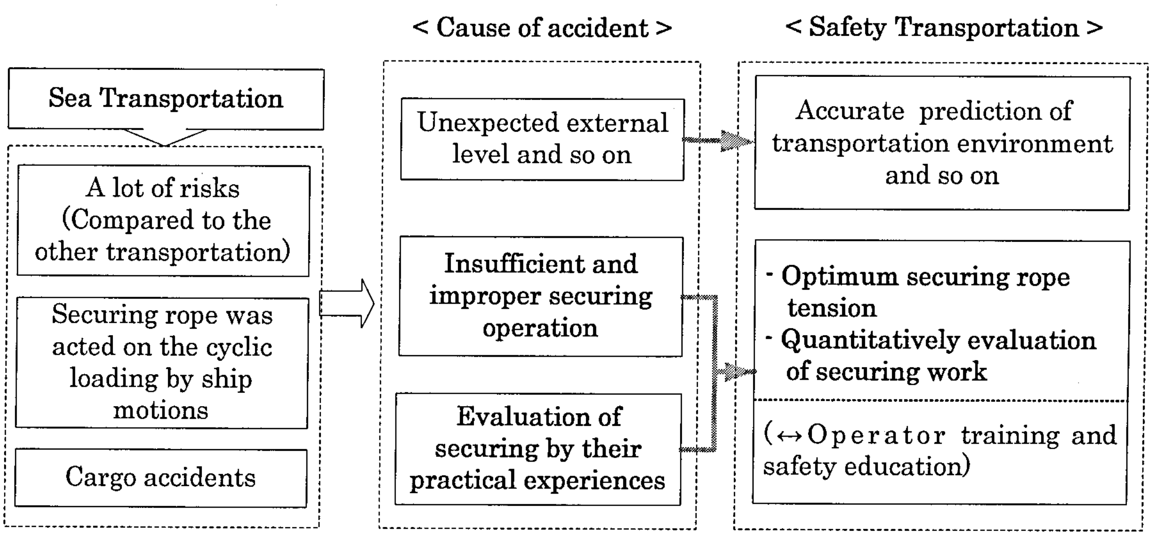

Figure 1-1 Consideration for safety transportation (Cargo handling and Securing)

1.3 Flow of this research

From 1 January 1998, in accordance with the SOLAS 1974 Chapter VI and VII and the CSS code, cargo securing manual was obliged on board to prevent of cargo accidents by the insufficient and improper securing. So, the operators usually decide the cargo handling methods based on the manual and their practical experience, for example arrangement of stowage, position of cargo loading bay and selection of the securing devices or methods, etc.

However, a lot of cargo accidents still occur due to the insufficient securing, and the securing rope tensions are checked according to the experience, there is a personal difference on a judgment. The lashings are to be inspected during the voyage to insure that proper tension is maintained.

According to the cargo securing manual, the securing devices are selected to evaluation of forces acting on cargo unit when subjected to the maximum rolling angle and metacentric height. But, it leaves much room for considerations, in case of the selection of the securing devices, because of those were acted on cyclic loading by the hull motions and a permanent stretch of the rope will be possible to causes the freight collapse and the movement accident. Also, due to uncertainties as to the actual weight and locations of the center of gravity of cargo units, and due to the difficulty in predicting dynamic accelerations and the complexity of dynamic calculations, the securing devices may vary considerably.

Figure 1-2 shows a process to set up an optimum tension of securing rope. First of all, the transport environments should be predicted by the voyage routes and vehicle. Also, the workers are operating base on the cargo securing manual for safety transportation, for example arrangement of stowage, position of cargo loading bay and selection of the securing devices or methods, etc. In addition, it is also necessary to the effort to education of technical improvement and the management system for the related field workers.

Next, the basic experiments are carried out that set up a securing cargo on the ship motion simulator for the prediction of fluctuation tension of securing rope by expected external force. As a result, it can be predicted the fluctuation tension of the rope in case of arbitrary initial tension and frequency (13).

When the fluctuation tension acts on the rope by the ship motions, the residual tension of securing rope decreasing rate is faster than it without the tension fluctuating. According to the cyclic loading test by the expected fluctuation tension, the residual tension of securing rope can be predicted (14).

Then we can evaluate the safety degree of securing by the predicted residual tension. Through this evaluating, we can set up the safety initial tension of securing rope provisionally. Afterward, it is revaluated at the destination for the comparison safety degree of provisional setting tension. Finally, the optimum initial tension of securing rope is actually applied to transportation and it can be applied to the securing operation of field workers like to tighten of securing ropes under transportation (15).

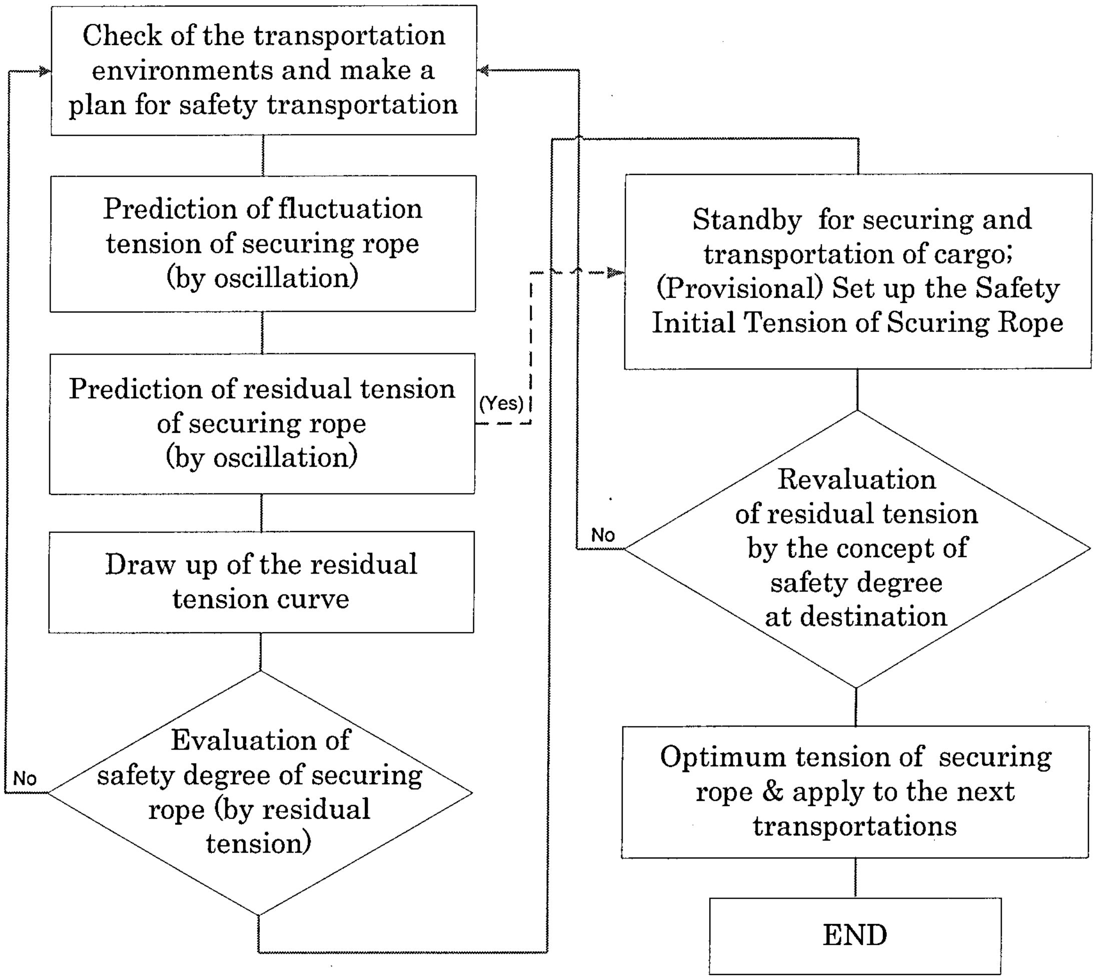

Figure 1-2 Flow to set optimum and evaluation of securing rope

1.4 Structure of this study

Figure 1-3 presents structure of this study.

Chapter 1 presents background and purpose, describes the structure of this study.

Chapter 2 shows the concept of appropriate packaging and secuirng to prevent cargo accidents by the stress occurred under transportation, and the concents of cargo securing manual brefly. Also, presents the result of field observation and questionaire survey.

Chapter 3, to prediction of fluctuation tension of securing rope, first of all, we though only so called roll and heave motions, and derived mathematical equations to calculate the force of securing rope. And then, was measured a chage of rope tension and motion of simulator at time series. Finally, predicted the fluctuation tension of the rope in case of arbitrary initial tension and freqeuency using the measured data. Also, the results of prediction were verified through the experiment.

Chapter 4, 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 loading. The residual tensions of two tests were in good agreement with each other. So, it can be predicted through the cyclic loading test in the estimated fluctuation tension with oscillation test by ship motion simulator.

Chapter 5, in order to the decision of optimum tension of securing rope, previously, we defined as safety degree by residual tension curve and is introduced to evaluate of the safety of rope tension, and through the concept of safety initial tension, proposed the setting method an optimum tension of securing rope with the aim of the prevent cago accidents by oscillation.

Finally, in Chapter 6, presents the conclusion of this dissertation and condideration.

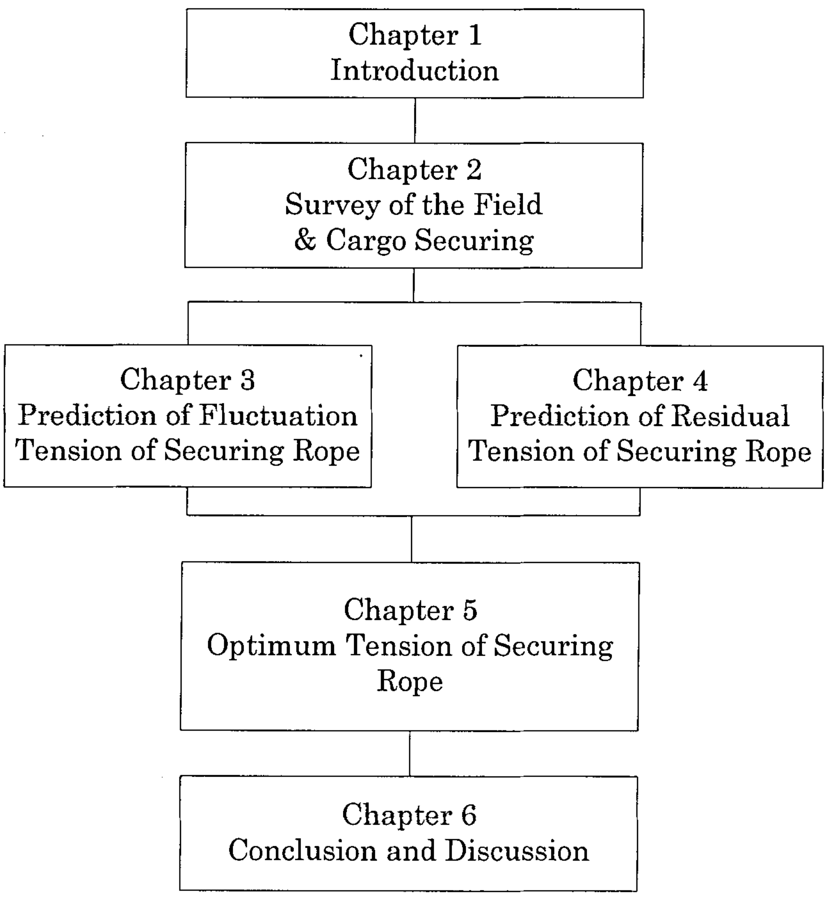

Figure 1-3 Structure of this study

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Chapter 2 Survey of the Field & Cargo Securing

2.1 Prologue

As mentioned in previous Chapter 1, the freights will reach the hands of consumers through the process of packing, loading, unloading and transport. To prevent the movement of cargo by the external forces in the transport, the freight was secured with the rope, band, chain, and so on.

However, according to statistics of the Japan Marine Accident Inquiry Agency (MAIA), about 170 cases of cargo accidents were occurred last 4 years (2004~2007) due to the inappropriate deck work or cargo work and defective stowage of cargo.

Accordingly, in this chapter presents the concept of appropriate packaging and securing to prevent cargo accidents by the stress occurred through the total process of physical distribution, and the method of assumption of external force based on the CSM.

Finally, presents the result of the observation of field and questionnaire survey for quantitative evaluation of the securing rope tension about the method and the flow of securing works, and do on.

2.2 Packaging and Physical distribution

- Survey of the transportation environment

The packaged and secured freights get a shock and the stress due to the environmental condition, impact, vibration and oscillation, and so on under transportation. For that reasons, the packaged freight was tested according to the rules and pay due regard to such factors in the process of packaging design.

In case of the marine transportation, the sea condition can be predicted by ocean wave statistics, and statistics data can be shared with easy distance from web site or over the internet in real-time. So, after due full consideration base on those sources, finally, the transport vehicle, voyage route, cargo securing arrangement, and so on is selected.

- Consideration of technical and management system

For the safety transportation, it is need not only proper or appropriate cargo stowage, securing and packaging, but also the consideration or support of technical and management system, for example, operator training and safety education with cargo treatment technique, development and application of new technology, and replacement of equipment.

2.2.1 Process of physical distribution

It is very important that the transportation of cargo to the destination safely and on time. To elevate the efficiency and safety of transportation, recently, the cargoes are unitized by the pallet and/or the container. Figure 2-1, 2-2 shows the flow of the cargo from production to consumption. 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. Such an accident have occurred fatal damage to not only the cargo but also the transport vehicle and environment. 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. 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. Therefore, it is more necessary to do the securing certainly to prevent accidents such as cargo movements and collapse due to the improper and insufficient lashing and arrangement of cargo in transportation.

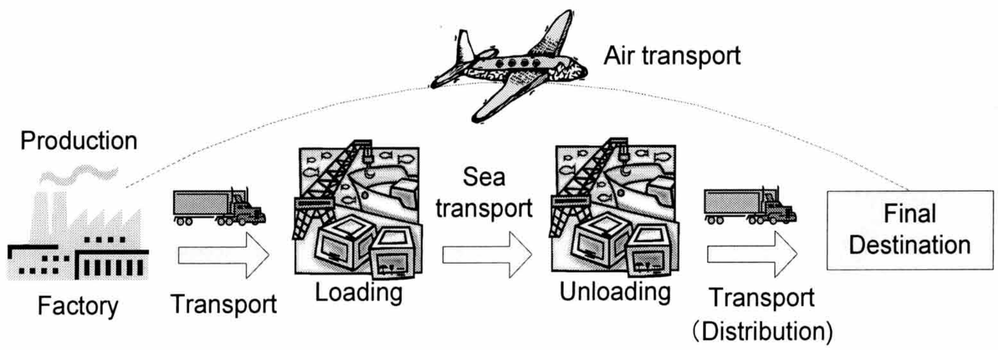


Figure 2- 1 Outline of transportation (Overseas transport)

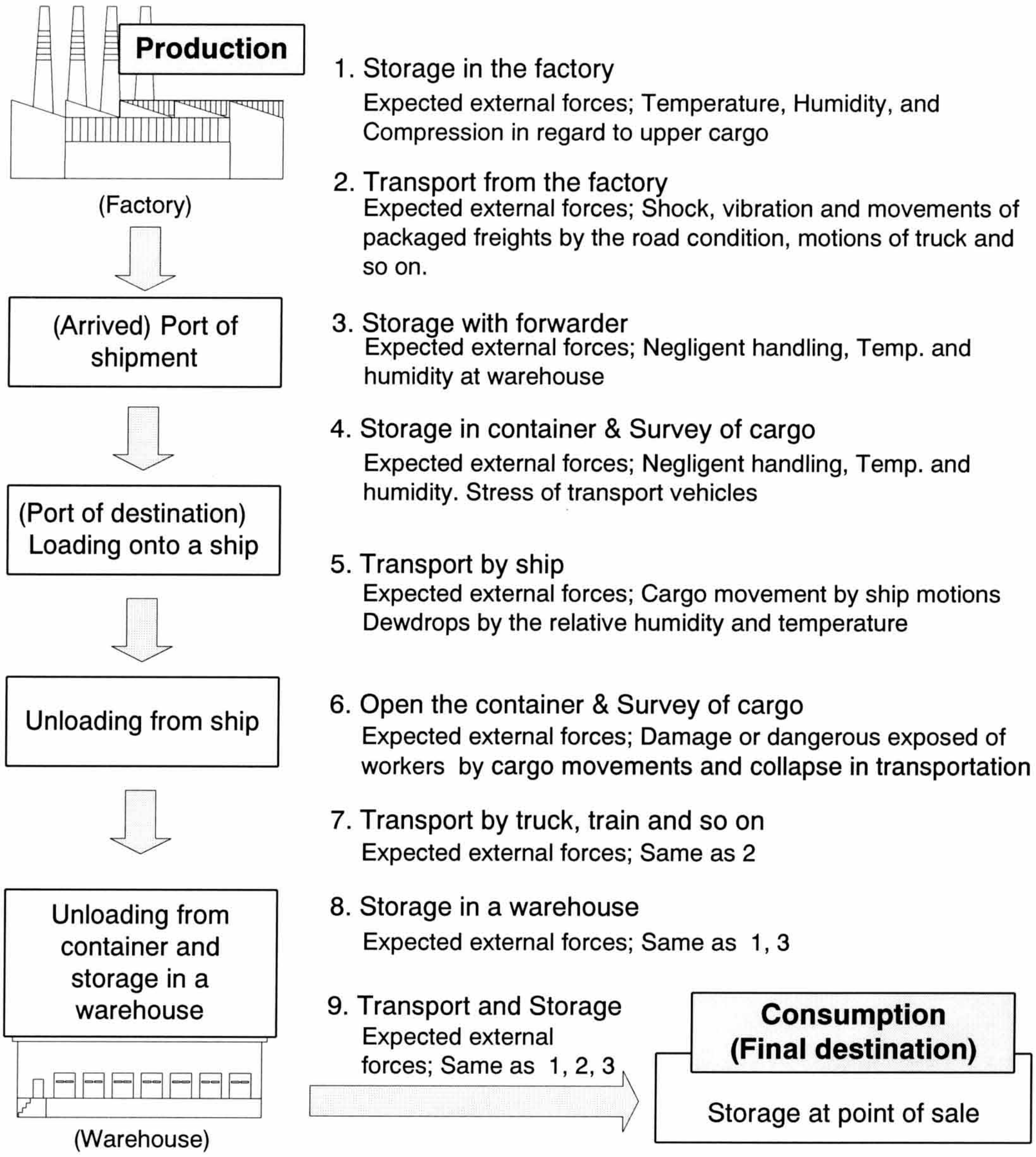


Figure 2- 2 Flow of the cargo from production to consumption (Sea transportation)

2.2.2 Appropriate packaging and securing

2.2.1.1 Stress and safety under transportation

The field of physical distribution has undergone a marked transformation over the past several years. To achieve lower costs, higher-level services and safety evaluation, the company service to customers using the distribution services system, for example, third party logistics (3PL) & third party maintenance (3PM).

Figure 2-3 illustrates the stress acted on cargo in transportation, and needed an appropriate packaging and sufficient securing for safety transportation. As shown in Fig. 2-3, the cargo is under stress like as vibration, oscillation, compression, and so on; especially, securing devices acted on cyclic loading by ship motions. Surprisingly, the important of securing is often noted but rarely study.

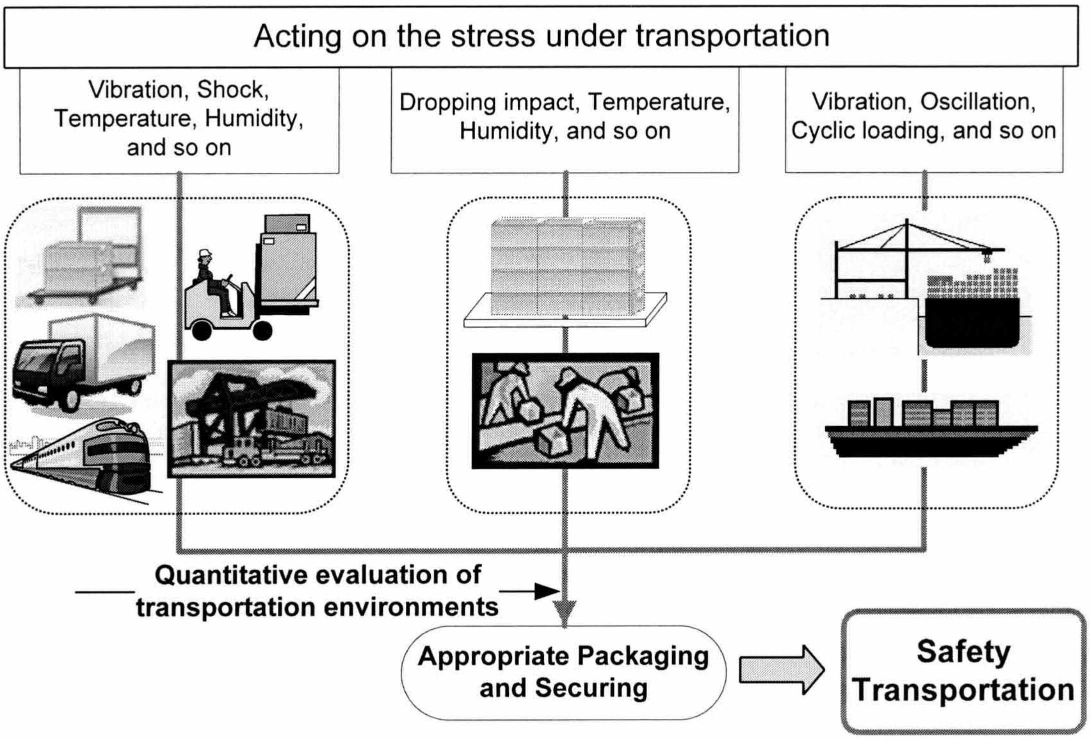


Figure 2- 3 Stress and safety under transportation

2.2.1.2 Design flow of appropriate packaging

Figure 2-4 shows the flow chart of product design for appropriate packaging, and Figure 2-5 shows the relationship between external force and goods, packaging. Preferentially, the product carried out the durability test under the distribution environment before the packaged. Next, as shown in Table 2.1, packaged freight will also take the tests in accordance with the rules, for example, ISO (International Organization for Standardization), JIS (Japanese Industrial Standards), ASTM (American Society of Testing Materials), and so on.

When the packaging test carried out under estimated external forces, it is required the selection and development of packaging material for protect cargo, too. Packaged freight is carried by transport vehicles, also, the packaging condition was revaluated through the measuring an actual distribution condition, and it leaves much room for consideration.

In this case, it is important to the selection of optimum packaging material under consideration of safety clearance, as shown in Fig. 2-5 [1].

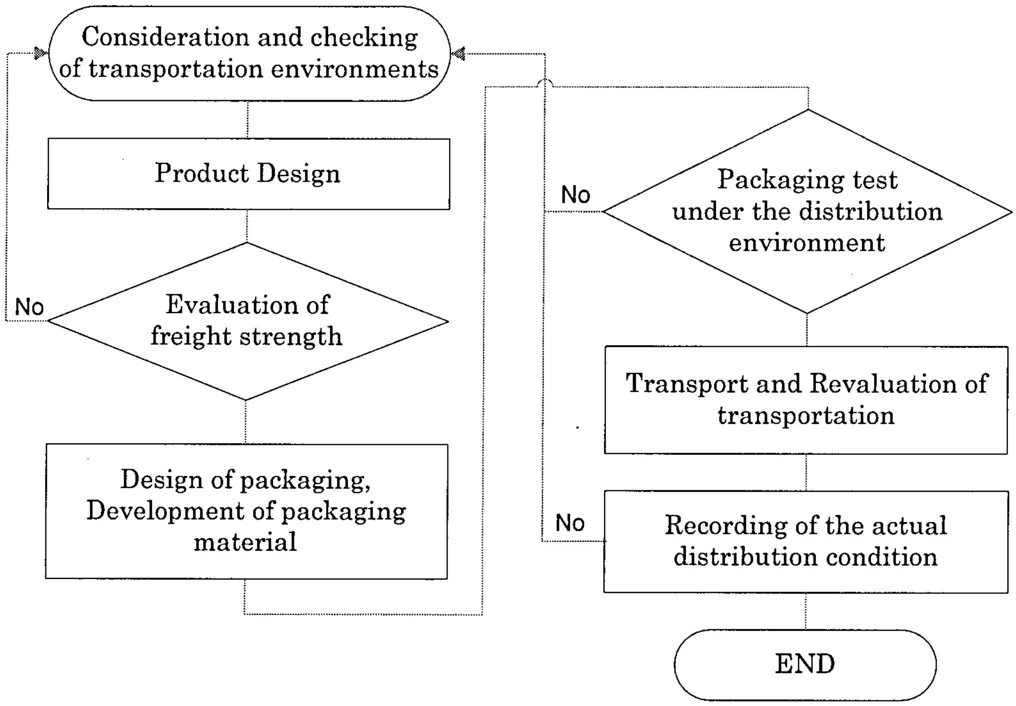


Figure 2- 4 Flow chart of product design for appropriate packaging

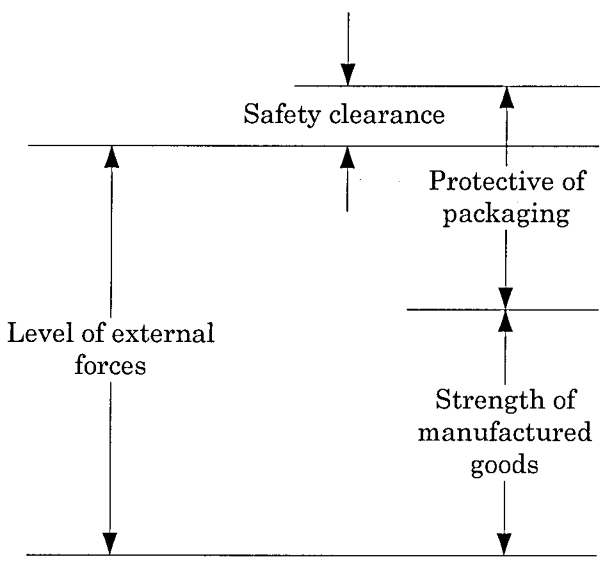


Figure 2- 5 Relationship between external forces and packaging

Table 2. 1 The test list of packaged freights in JIS

JIS	Title
Z 0108 : 2005	Glossary of terms for packaging
Z 0119 : 2002	Mechanical – shock fragility testing methods for packaging and products design
Z 0170 : 1998	Unit loads – Stability testing
Z 0200 : 1999	Packaged freights – General rules of testing
Z 0201 : 1989	Methods of Designating on Component Parts and Points of Containers when Testing
Z 0202 : 1994	Method of drop test for packaged freights
Z 0203 : 2000	Packaged freights – Conditioning for testing
Z 0205 : 1998	Packaged freights – Method of horizontal impact tests
Z 0212 : 1998	Packaged freights and containers – Method of compression test
Z0232 : 2004	Packaged freights – Method of vibration test
Z0235 : 2002	Cushioning materials for packaging – Determination of cushioning performance
Z0240 : 2002	Structural cushioning materials for packaging – Determination of cushioning performance

2.2.3 Statistics survey of ocean wave

A statistics survey of wave characteristics estimated visually from voluntary observing ship sailing along the shipping routes of the world.

The selection of sea areas for which tables are presented, was made by studying a Marsden Square Chart(Marsden Squares are 10° squares, each having a code number), and first noting all the squares in which the sample of observations is reasonably large, since these all must lie on well-frequented shipping routes. These squares have then been arranged into 50 groups chosen so that conditions should be fairly homogenous within each group. They are shown on the map, grouping of Marsden Squares into areas, Figure 2-6, 2-7. Marsden squares have mostly been used for identifying the geographic position of meteorological data, and are described further in various publications of the World Meteorological Organization (WMO) [(2)].

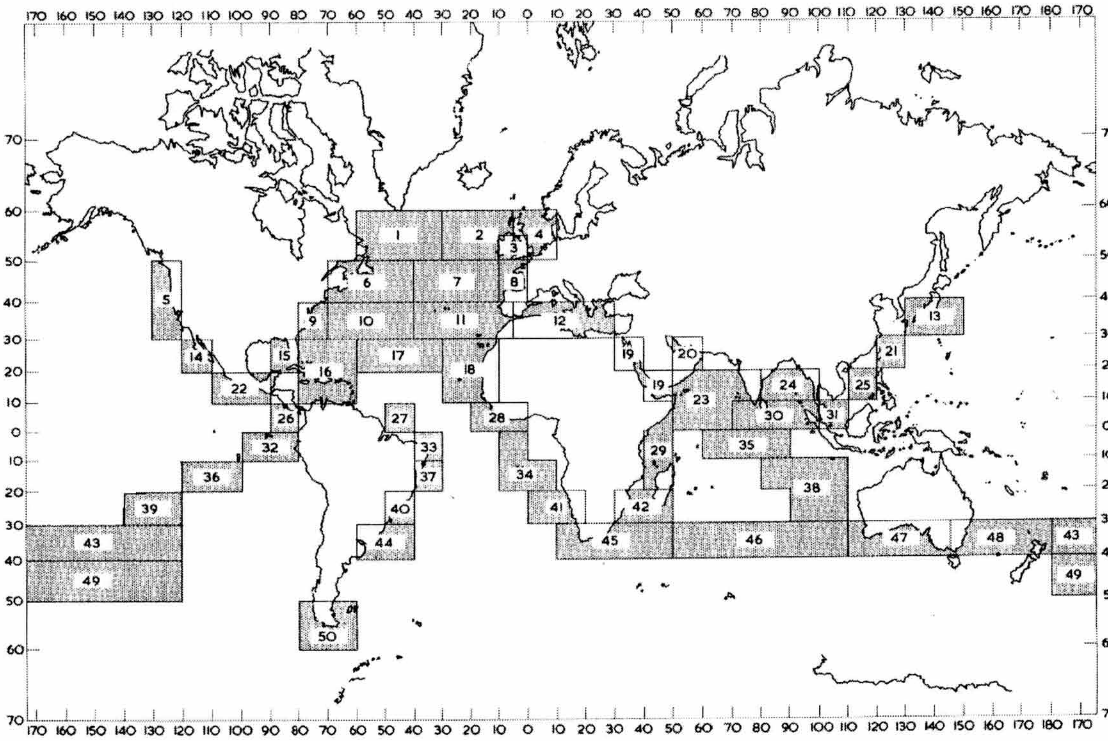


Figure 2- 6 Grouping of Marsden Squares into areas

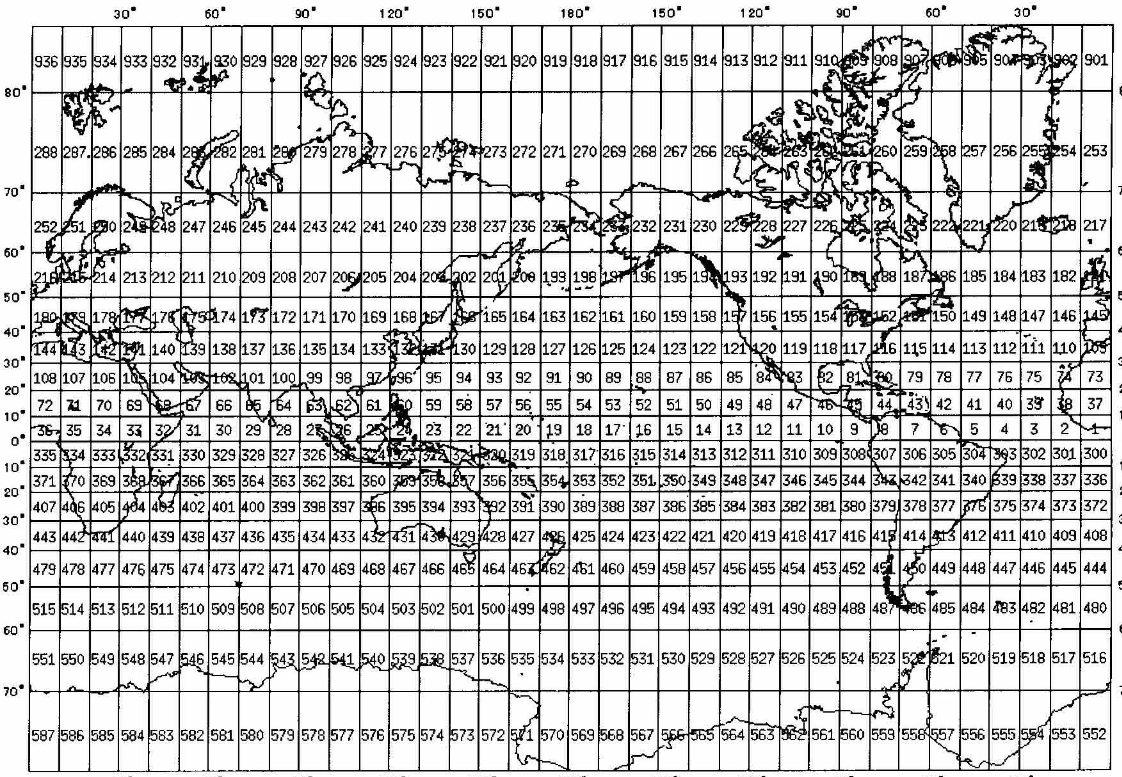
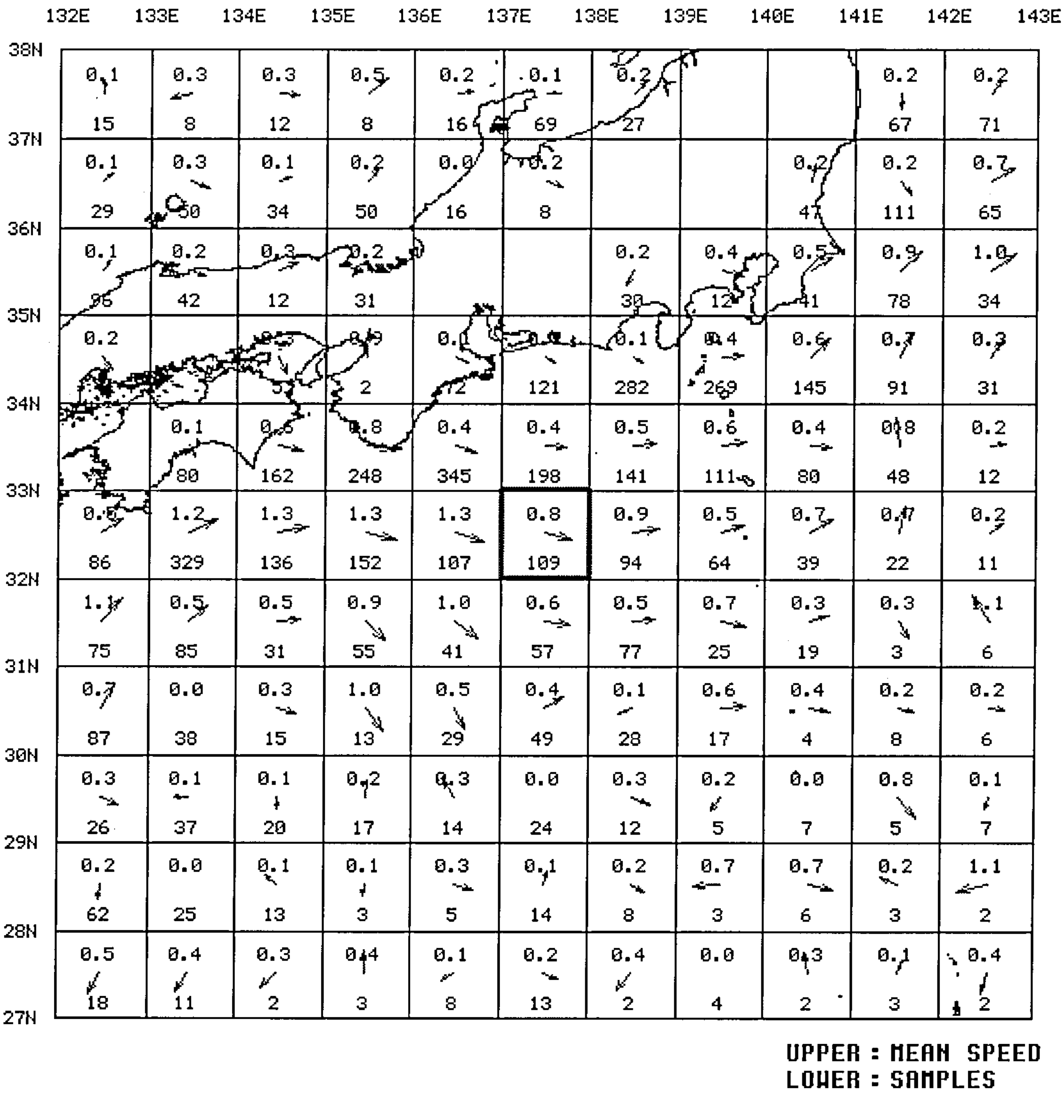


Figure 2- 7 Marsden Square Chart

For example, Japan Oceanographic Data Center (JODC) is collecting the ocean data from visual observations on the vessels in Japanese waters and wave data taken at 51 points along Japanese coast including the vessel weather report points by the use of vision or measuring devices [3]. Also, acquires foreign data through the international oceanographic data and information exchange system (IODE).

Moreover, Japan Meteorological Agency (JMA) is operating the NEAR-GOOS (North-East Asian Regional-Global Ocean Observing System) Regional Real Time Database for the exchange of oceanographical data among the participating institutions, and it's being implemented by China, Japan, the Republic of Korea and the Russian Federation. Statistics of wave data contains a lot of useful information; Temperature and salinity, ocean current, tidal current, frequency of appearance of wind, wind wave and swell cover a 1-degree mesh of latitude 20 ~ 50 degrees north and longitude 120 ~ 150 degrees east. Also, The JODC operates J-DOSS (JODC Data On-line Service System), which is an on-line oceanographic data or information retrieval system. The oceanographic data are downloaded through J-DOSS.

Figure 2-8 show the example of statistics data of ocean current in 1 degree. As indicated by ocean statistical data, it can be predicted the status of the sea, and it is need to the intensive preparation provide against the external forces occurred in sea-wave, too.



Data Informations (Ocean current)

- Latitude : 32.00N - 33.00N	- Longitude : 137.00E - 138.00E
- Mean Current Speed (knots) : 0.8	- Mean Direction (deg.) : 109
- Max Current Speed (knots) : 3.9	- Max Direction (deg.) : 120
- Stability (percent) : 64	- Number of Sample : 109

Figure 2- 8 Statistics of ocean current in 1 degree (January)

2.3 Cargo securing manual

Regulations VI and VII of the 1974 SOLAS Convention require cargo units and cargo transport units to be loaded, stowaged and securing throughout the voyage in accordance with a CSM approved by the administration and drawn up to a standard at least equivalent to the guidelines developed by the organization, ref. IMO MSC/Circ. 745.

Moreover, member governments are invited to bring these guidelines to the attention of all parties concerned, with the aim of having cargo securing manual carried on board ships prepared appropriately and in a consistent manner, and to implement them as soon as possible and, in any case, not later than 31 December 1997.

All cargo ships, regardless of tonnage, except those engaged solely in the carriage of either liquid or solid bulk cargoes are to be provided with a cargo securing manual approved by the flag administration, as required by SOLAS 1974.

2.3.1 Contents of CSM

The contents of CSM are summarized as followings.

① Securing devices and arrangements;
Specification for fixed and portable cargo securing devices, inspection and maintenance schemes

② Stowage and securing of non-standardized and semi-standardized cargo;
Handling and safety instructions, evaluation of forces acting on cargo units, application of portable securing devices on various cargo units, vehicles and stowage blocks, supplementary requirements for RO-RO ships

③ Stowage and securing of containers and other standardized cargo;
Handling and safety instructions, stowage and securing instructions, other allowable stowage patterns, forces acting on cargo units

④ Calculation strength of securing equipment in according with Annex 13 to the CSS code 2003 edition from IMO

2.3.2 Cargo stowage, lashing and securing arrangements

The cargo securing manual specifies arrangements and cargo securing devices provided on board the ship for the correct application to and the securing of cargo units, containers, vehicles and other entities, based on transverse, longitudinal and vertical forces which may arise during adverse weather and sea conditions.

The cargo securing devices should be applied so as to be suitable and adapted to the quantity, type of packaging, and physical properties of the cargo to be carried.

It is imperative to the safety of the ship and the protection of the cargo and personnel that the securing of the cargo is carried out properly and that only appropriate securing points or fitting should be used for cargo securing.

Figure 2-9, 2-10 presents an analysis process of cargo stowage, lashing and securing arrangements system [4]. The securing equipment (for example, type, quantity and so on) was selected by calculation of required strength in accordance with Annex 13 to the CSS code as shown in Fig. 2-9, 2-10.

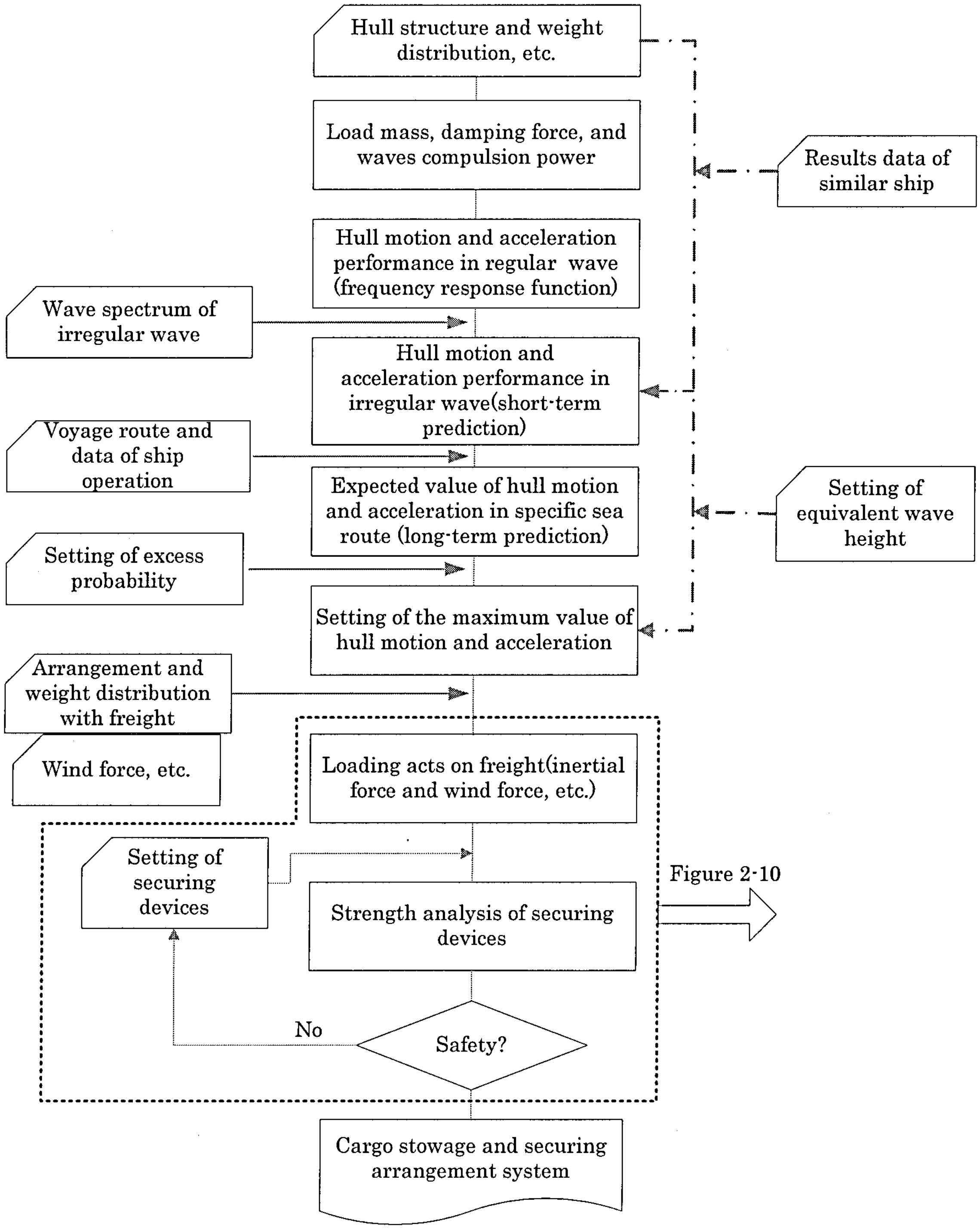


Figure 2- 9 Analysis of the cargo stowage and securing arrangement (a)

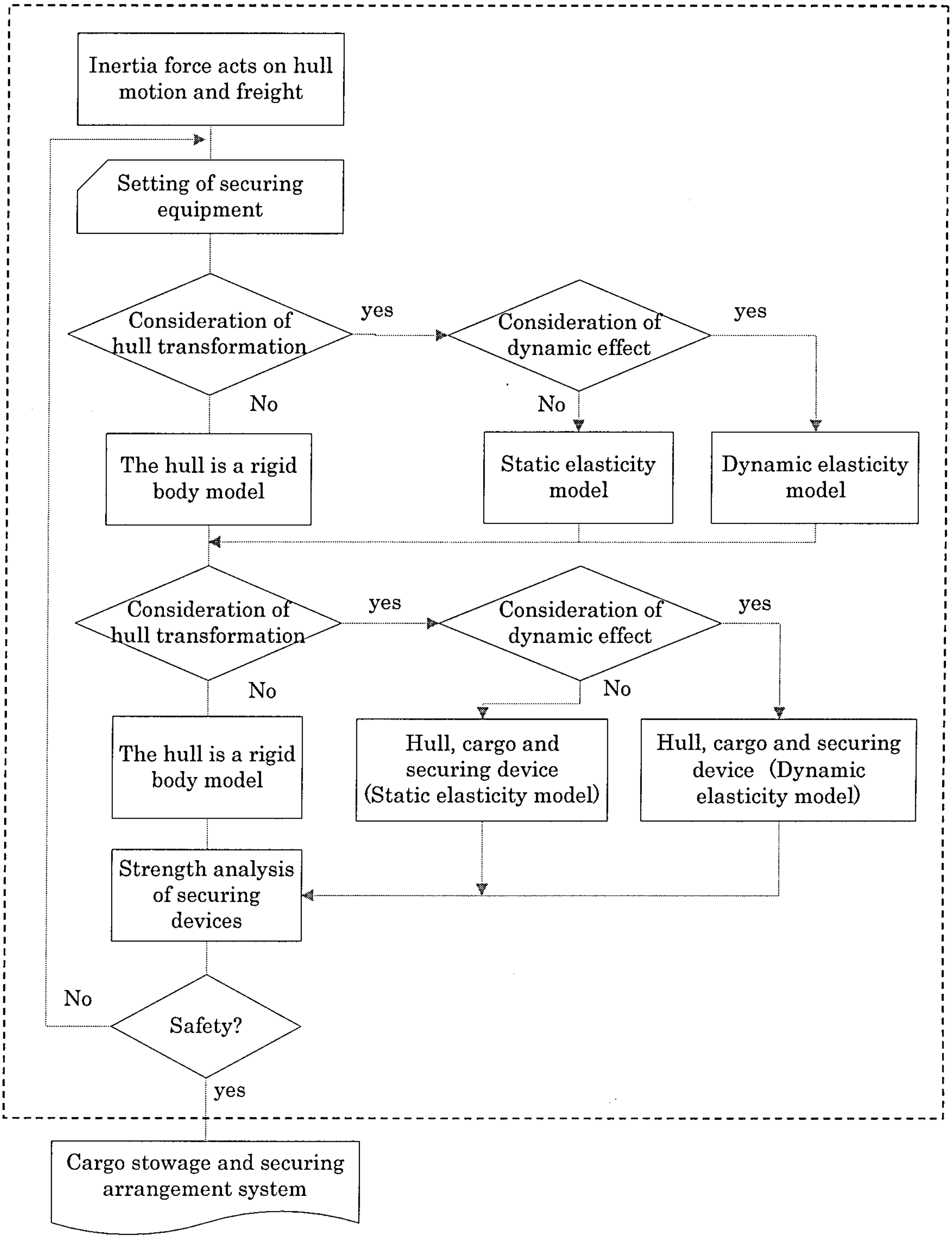


Figure 2- 10 Analysis of the cargo stowage and securing arrangement (b)

2.3.3 Determination of forces for container securing arrangements

① The forces action in the securing system is to be determined for each loading condition and associated set of motions of the ship.

② The following forces are to be taken into account; Static gravity forces / Inertial forces generated by accelerations due to roll, pitch and heave motions of the ship / Wind forces / Forces imposed by the securing arrangements / Wave impact forces.

③ Where ship response data is not available the values for roll, pitch and heave as given in Table 2.2 will be used for the calculation.

④ The individual components of force due to gravity, wind and ship motions acting on a particular container are to be determined in accordance with Table 2.3 and Figure 2-11 [5].

⑤ Safety factor; Within the assessment of a securing arrangement by a calculated balance of forces and moments, the Calculated Strength (CS) of securing devices should be reduced against Maximum Securing Load (MSL), using a safety factor of 1.5, as follows;

$$CS = \frac{MSL}{1.5}$$

The reasons for this reduction are the possibility of uneven distribution of forces among the devices, strength reduction due to poor assembly and others. Notwithstanding the introduction of such a safety factor, care should be taken to use securing elements of similar material and length in order to provide a uniform elastic behavior within the arrangement.

⑥ The symbols of Table 2.2, 2.3 and Fig. 2-11 definitions are as following.

- a = Breadth of the container, in meters
- b = Length of the container, in meters
- e = Base of natural logarithms, 2.7183
- GM = Transverse metacentric height of the ship in the container load condition, in meters.
- x = Longitudinal horizontal distance from 0, to the centre of the container, in meters
- y = Transverse horizontal distance from the center line of the ship to the centre of the container, in meters
- Z_m = Vertical distance from 0, to the centre of gravity of the container, in meters
- A = Projected side area of the container, in m^2

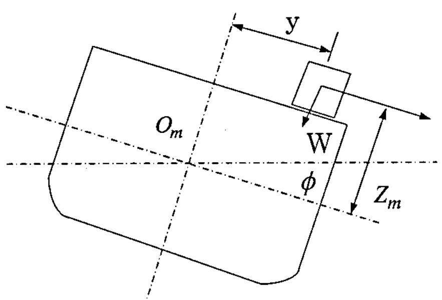
- B = Molded breadth of the ship, in meters
- D = Molded depth of the ship, in meters
- L_{pp} = Length between perpendiculars of the ship, in meters
- O_m = Centre of motion
- T_c = Molded draught in the container load condition, in meters
- T_h = Full period of heave of the ship, in seconds
- T_p = Full period of pitch of the ship, in seconds
- T_r = Full period of roll of the ship, in seconds
- V = Wind speed, in m/s
- W = Design weight of the container and contents
- ϕ = Maximum single amplitude of roll, in degrees
- ψ = Maximum single amplitude of pitch, in degrees

Table 2. 2 Ship motions

Motion	Maximum single amplitude	Periods, in seconds
Roll	$\phi = \sin^{-1}\theta$ Degrees but need not exceed 30° and is not to be taken less than 22° Where, $\theta = \sin\phi$ $= \left(0.45 + 0.1\frac{L}{B}\right)\left(0.54 - \frac{L}{1270}\right)$	$T_r = \frac{0.7B}{\sqrt{GM}}$
Pitch	$\psi = 12e^{-0.0033L_{PP}}$ but need not exceed 8°	$T_P = 0.5\sqrt{L_{PP}}$
Heave	$\frac{L_{PP}}{80}m$	$T_h = 0.5\sqrt{L_{PP}}$

Table 2. 3 Components of forces

Source		Component of force, in tones: Pressure (normal to deck)	Sliding (parallel to deck): transverse	Sliding (parallel to deck): longitudinal
Static	Roll	$W\cos\phi$	$W\sin\phi$	
	Pitch	$W\cos\psi$		$W\sin\psi$
	Combined	$W\cos(0.71\phi)\cos(0.71\psi)$	$W\sin(0.71\phi)$	$W\sin(0.71\psi)$
Dynamic	Roll	$0.07024W\frac{\phi}{T_r^2}y$	$0.07024W\frac{\phi}{T_r^2}z_m$	
	Pitch	$0.07024W\frac{\psi}{T_p^2}x$		$0.07024W\frac{\psi}{T_p^2}z_m$
Heave	Roll	$0.05W\frac{Lpp}{T_h^2}\cos\phi$	$0.05W\frac{Lpp}{T_h^2}\sin\phi$	
	Pitch	$0.05W\frac{Lpp}{T_h^2}\cos\psi$		$0.05W\frac{Lpp}{T_h^2}\sin\psi$
Wind			$8.25AV^2\cos\phi\times10^{-5}$	



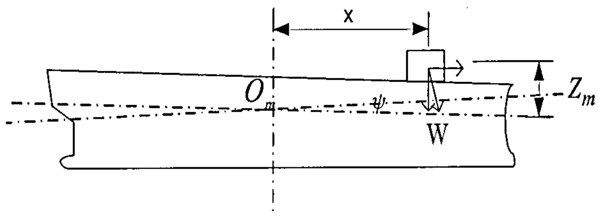


Figure 2- 11 Diagrammatic representation of motion

2.3.4 Assumption of external force

External forces to a cargo unit in longitudinal, transverse and vertical directions should be obtained using the formula 2-1.

$$F_{(x,y,z)} = m \cdot a_{(x,y,z)} + F_{w(x,y)} + F_{s(x,y)} \tag{2-1}$$

Where,

$F_{(x,y,z)}$ = longitudinal, transverse and vertical forces

m = mass of the unit

$a_{(x,y,z)}$ = longitudinal, transverse and vertical accelerations

$F_{w(x,y)}$ = longitudinal, transverse forces by wind pressure

$F_{s(x,y)}$ = longitudinal, transverse forces by sea sloshing

The basic acceleration data are presented in Table 2.4.

Table 2. 4 Basic acceleration data

Transverse acceleration a_y in m/s^2										Longitudinal acceleration a_x in m/s^2
on deck, high	7.1	6.9	6.9	6.7	6.7	6.8	6.9	7.1	7.4	3.8
on deck, low	6.5	6.3	6.1	6.1	6.1	6.1	6.3	6.5	6.7	2.9
tween-deck	5.9	5.6	5.5	5.4	5.4	5.5	5.6	5.9	6.2	2.0
lower hold	5.5	5.3	5.1	5.0	5.0	5.1	5.3	5.5	5.9	1.5
0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	L
Vertical acceleration a_z in m/s^2										
	7.6	6.2	5.0	4.3	4.3	5.0	6.2	7.6	9.2	

The basic acceleration data are to be considered as valid under the following operational conditions:

- Operation in unrestricted area;

- Operation during the whole year;
- Duration of the voyage is 25 days;
- Length of ship is 100 m;
- Service speed is 15 knots;
- B/GM ≥ 13 (B: breadth of ship, GM: metacentric height)

For ships of a length other than 100 m and a service speed other than 15 knots, the acceleration figures should be corrected by a factor given in Table 2.5.

Table 2. 5 Correction factors for length and speed

Length [m] / Speed [kts]	30	40	50	60	70	80	90	100	120	140	160	180	200	250	300
9	1.37	1.31	1.20	1.09	1.00	0.92	0.85	0.79	0.70	0.63	0.57	0.53	0.49	0.41	0.36
12	1.56	1.47	1.34	1.22	1.12	1.03	0.96	0.90	0.79	0.72	0.65	0.60	0.56	0.48	0.42
15	1.75	1.64	1.49	1.36	1.24	1.15	1.07	1.00	0.89	0.80	0.73	0.68	0.63	0.55	0.48
18	1.94	1.80	1.64	1.49	1.37	1.27	1.18	1.10	0.98	0.89	0.82	0.76	0.71	0.61	0.54
21	2.13	1.96	1.78	1.62	1.49	1.38	1.29	1.21	1.08	0.98	0.90	0.83	0.78	0.68	0.60
24	2.32	2.13	1.93	1.76	1.62	1.50	1.40	1.31	1.17	1.07	0.98	0.91	0.85	0.74	0.66

2.3.4.1 Transverse sliding

The balance calculation should meet the following condition

$$F_y \le \mu \cdot m \cdot g + CS_1 \cdot f_1 + CS_2 \cdot f_2 + \cdots + CS_n \cdot f_n \qquad (2\text{-}2)$$

Where,

n is the number of lashing being calculated

F_y is transverse force from load assumption(kN)

μ is frictional coefficient

μ =0.4 for timber-timber, wet or dry

μ =0.3 for steel-timber or steel-rubber

μ =0.1 for steel-steel, dry

μ =0.0 for steel-steel, wet

m is mass of the cargo unit(t)

g is gravity acceleration of earth=9.8 m/s^2

CS is calculated strength of transverse securing devices (kN)

f is a function of μ and the vertical securing angle α

Table 2. 6 f-values as a function of a and μ

μ \ α	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°
0.3	0.72	0.84	0.93	1.00	1.04	1.04	1.02	0.96	0.87	0.76	0.62	0.47	0.30
0.1	0.82	0.91	0.97	1.00	1.00	0.97	0.92	0.83	0.72	0.59	0.44	0.27	0.10
0.0	0.87	0.94	0.98	1.00	0.98	0.94	0.87	0.77	0.64	0.50	0.34	0.17	0.00

Remark: f= μ sinα+cosα

2.3.4.2 Transverse tipping

This balance calculation should meet the following condition

$$F_y \cdot a \le b \cdot \mu \cdot m \cdot g + CS_1 \cdot c_1 + CS_2 \cdot c_2 + \cdots + CS_n \cdot c_n \quad (2\text{-}3)$$

Where,

F_y, m, g, CS are as explained (2.3.4.1)

a is lever-arm of tipping(m)

b is lever-arm stableness(m)

c is lever-arm of securing force(m)

2.3.4.3 Longitudinal sliding

Under normal conditions the transverse securing devices provide sufficient longitudinal components to prevent longitudinal sliding. If in doubt, a balance calculation should meet the following condition:

$$F_x \le \mu(m \cdot g - F_z) + CS_1 \cdot f_1 + CS_2 \cdot f_2 + \cdots + CS_n \cdot f_n \quad (2\text{-}4)$$

Where,

F_x is longitudinal force from load assumption(kN)

μ , m, g, f, n are as explained (2.3.4.1)

F_z is vertical force from load assumption(kN)

CS is calculated strength of longitudinal securing devices (kN)

Remark: Longitudinal components of transverse securing devices should not be assumed greater than 0.5CS

Figure 2-12, 2-13 shows an example of the result using the lashing calculation arrangement program. The program calculates accelerations and balance of forces in semi- standardized and non-standardized lashing arrangements (i.e. cargo units other than containers) in accordance with Annex 13 to the CSS code 2003 edition from IMO (6). Using the software program, the external forces to a cargo unit in longitudinal, transverse and vertical directions should be obtained more easily.

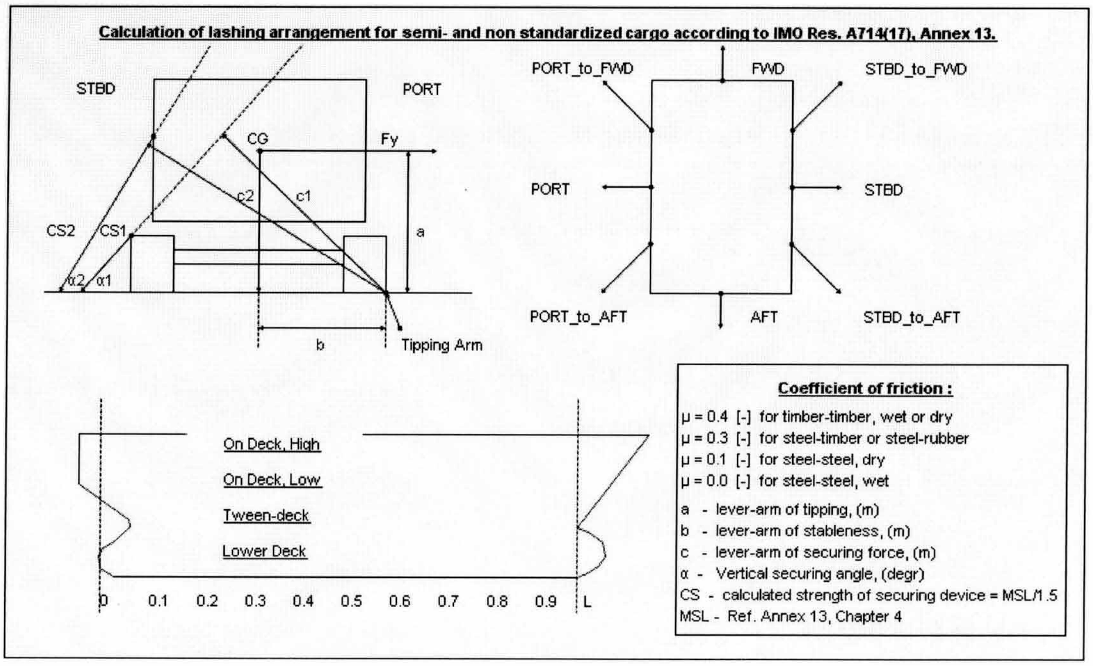


Figure 2- 12 Caculation of lashing arrangement

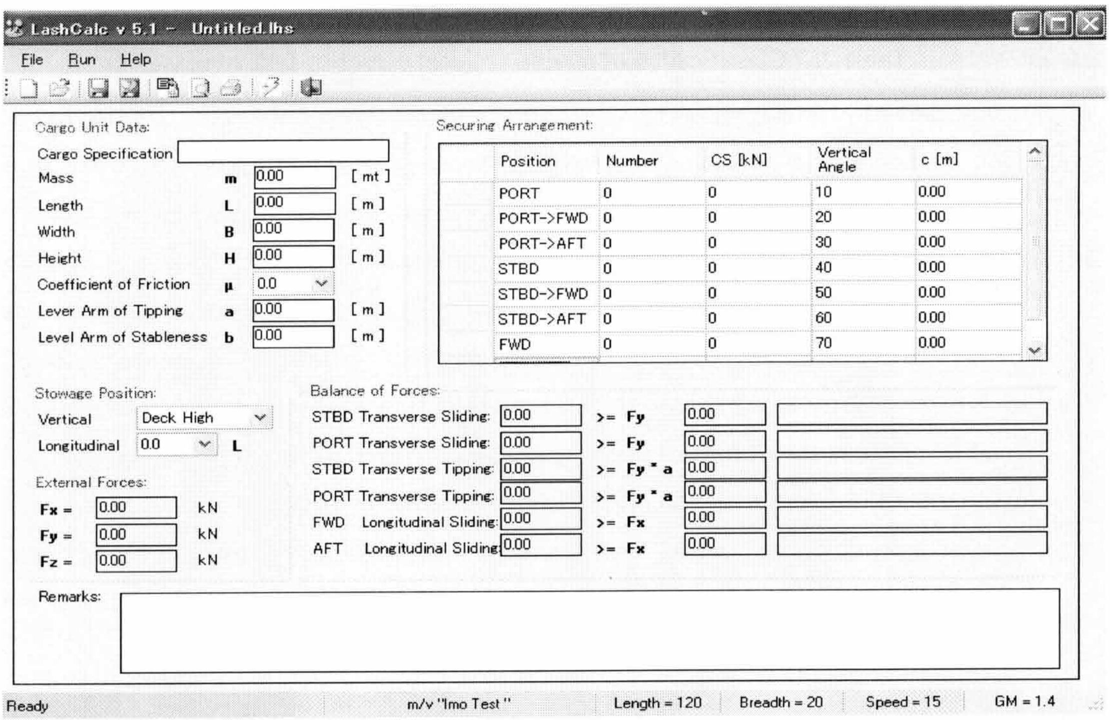


Figure 2- 13 Example of the lashing calculation

2.4 Marine casualty

According to the Japan MAIA, marine casualty means an event or process, which causes or poses the threat of :

(a) Death or serious injury to a person ;

(b) The loss of a person overboard ;

(c) Significant loss or stranding of, or damage to, or collision with, a vessel or property ; or

(d) Significant damage to the environment

2.4.1 Analyses of marine casualties

To clarify the causes of marine accidents and to thereby contribute to the prevention of their occurrence, the marine accident inquiry is very important. Under Table 2-7, 2-8 shows a statistical data of marine casualties by Japan MAIA [7]. According to Japan MAIA, about 170 cases of marine accident occurred last 4 years due to the inappropriate deck work or cargo work(Case A), and defective stowage of cargo(Case B), and the number of cases is about 3.3 percentage of the total accident cases.

Table 2. 7 Classification of marine accident causes by type of vessel

(Number of cases)

Type of vessel / *Year(case)*		Passenger ship	Cargo ship	Oil tanker	Fishing vessel	Tug boat	Pusher	Work boat	Pilot boat	Deck barge	Sport fishing boat	Transport boat for fishing	Transport vessel	Pleasure boat	Others	Sum(A+B) / Total accident causes
2007	A	3	2	1	8	7		1		1				3	6	46/1329
	B				1						3	1	1	8		
2006	A	5	11	2	5	2		4			2			2	2	43/1264
	B	2			1						2			3		
2005	A	1	6		10	3	3	1						2	1	32/1255
	B	1									1			3		
2004	A	5	2		18	4	5	2	1					4	2	50/1387
	B	1			2		1				1		1	1		
Sum		18	21	3	45	16	9	8	1	1	9	1	2	26	11	171/5235

Table 2. 8 Classification of marine accident causes by category of accident

(Number of cases)

Type of accident / Year(case)		Collision	Collision(single)	Grounding	Capsize	Miscellaneous accident	Fire	Equipment damage	Deaths and injuries	Navigation hindrance	Flooding	Foundering	Explosion	Machinery failure	Facility damage	Sum(A+B) / Total accident causes
2007	A		1	1	5		1	2	19	1				1	1	46/1329
	B	1			2	1			10							
2006	A		1		3	1			24		4		2			43/1264
	B		1		2				5							
2005	A		1		3		1		19			2	1			32/1255
	B								4		1					
2004	A	1	2	5	3	3	1	22	1	5						50/1387
	B			1				6								
Sum		2	6	7	18	5	3	30	82	6	5	2	3	1	1	171/5235

2.4.2 Cargo securing and accident

The objects to be loaded must be fundamentally safe and secure and should not be able to move as a result of external effects that can be expected under normal operating conditions by the selecting securing methods, using securing materials, and do on. The only way to prevent damage from arising is by packing and unpacking in a professional manner and by using appropriate packing and securing methods.

Figure 2-14 shows example of cargo securing; Coil of 16t in a container without bedding fixed poorly by wedges and timbers and secured by soft iron wire (a), two coils of 12t each in Coil-Tainer (b), cover with canvas and secured by steel strap (c) [8].

Figure 2-15 shows example of cargo accident; Hole of container due to the movement of inside goods (a), Separation from the securing device and drop to the sea caused by in action of external force (b, c).

(a) (b) (c)

Figure 2- 14 Example of cargo securing

(a) (b) (c)

Figure 2- 15 Example of cargo accident

(Sources by Web site)

2.5 Questionnaire survey

The securing works is done to prevent the movement and the collapse of cargo in transport, but the cycling loading acts on lashing rope and freights by external force unavoidable generation it when transported.

Because of this, the securing works shall be to appropriate and sufficient from the beginning. In case of the securing rope tension, it will be occurred the personal differences by reason of the securing work is conducted by the operator. 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.

The tension of securing rope and residual tension are decreasing little by little acted on the cyclic loading by hull motions, and the safety transport of freight is not guaranteed.

Therefore, the securing works is necessary to do certainly through the quantitative evaluation of the securing rope tension. The actual securing method and the flow were grasped through the survey of field.

2.5.1 Investigation of field

The survey of field in regard to the securing work and tension of securing rope for set the optimum tension of securing rope through the observation of field and questionnaire is as follow.

- Respondent; 11 people

- Experience in the field;

Under 3 years	*3 ~ 5 years*	*5 ~ 10 years*	*Over 10 years*
4	2	2	3

- Main contents of questionnaire
  (Ⅰ) Whether the using of cargo securing manual or not
  (Ⅱ) Method of cargo securing
  (Ⅲ) Method of check and set up the securing rope tension

2.5.2 Result of questionnaire survey and analyses

① Whether the using of cargo securing manual or not

▪ Understood of contents and Using Manual	0
▪ Understood of contents, but not using Manual	1
▪ Not understood of contents	10

② Not understood of contents

▪ Education has not been received	8
▪ Others (It doesn't know existence)	2

③ Method of cargo securing

▪ Based on the cargo securing manual	1
▪ Based on the company manual	4
▪ Judgment of long experience	5
▪ Other(Entrusts to the expert)	1

④ Set up the initial tension of securing rope

▪ As high tension as possible	2
▪ Appropriate tension by the experience	3
▪ Appropriate tension refers to breaking strength	5
▪ Other(Entrusts to the expert)	1

⑤ Checking of the initial tension after securing work

▪ Sense by my experience	6
▪ Measuring by the devices	1
▪ Especially, it doesn't check	3
▪ Other(Judgment of person in charge of work)	1

⑥ Checking of the residual tension after securing work

▪ Sense by my experience	3
▪ Measuring by the devices	0
▪ Especially, it doesn't check	6
▪ Other(Judgment of person in charge of work)	2

2.6 Conclusion

To prevent cargo accident like above case, the securing operation should consider residual tension and fluctuation tension of securing rope by act on cyclic loading when assumption of external force based on the CSM.

Based on the presented, the obtained results are summarized below.

(1) For the safety transportation, it is need not only proper securing, appropriate packaging, but also the consideration or support of technical and management system, for example, operator training and safety education with cargo treatment technique, the development and application of new technology, and replacement of equipment.

(2) 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. Moreover, it is necessary to do the securing certainly to prevent accidents such as cargo movements and collapse in transportation.

(3) As indicated by ocean statistical data, it can be predicted the status of the sea, and it is need to the intensive preparation provide against the external forces occurred in sea-wave, too.

(4) The Cargo Securing Manual specifies arrangements and cargo securing devices provided on board the ship for the correct application to and the securing of cargo units, containers, vehicles and other entities, based on transverse, longitudinal and vertical forces which may arise during adverse weather and sea conditions.

(5) Assumption of External forces to a cargo unit in longitudinal, transverse and vertical directions should be obtained using the formula, as shown in Chapter 2.3.3.

(6) If the use the software program in accordance with Annex 13 to the CSS code 2003 edition from IMO, the external forces to a cargo unit in longitudinal, transverse and vertical directions should be more easily calculated. Actual stowage and securing plan must then be checked against the ship's computer loading/lashing program and/or CSM to ensure that permissible limits are not exceeded.

(7) According to this data, about 170 cases of marine accident occurred last 4 years due to the inappropriate deck work or cargo work(Case A), and defective stowage of cargo(Case B), and the number of cases is about 3.3 percentage of

the total accident cases.

(8) It leaves much room for considerations, in case of the selection of the securing devices, because of those were acted on cyclic loading by the hull motions and a permanent stretch of the rope will be possible to causes the freight collapse and the movement accident.

(9) As see the result of observation of field and questionnaire, the operators usually decide the cargo handling methods based on the manual and their practical experience.

(10) 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. For the safe transportation, therefore, setting of the optimum tension of securing rope is necessary to do certainly through the quantitative evaluation.

References

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(5) American Bureau of Shipping (1988), "Guide for Certification of Container Securing Systems", Section 3 Container Securing Arrangements.

(6) http://www.xcba.com/docs/cargo_office/index.html?userguidelashing.htm

(7) Japan MAIA (Marine Accident Inquiry Agency), http://www.mlit.go.jp/

(8) GDV Container Handbook, http://www.containerhandbuch.de/chb_e/index.html

Chapter 3 Prediction of Fluctuation Tension of Securing Rope

3.1 Prologue

It is very important that the transportation of cargo to the destination safely and on time. If there is not a change of tension of securing rope, cargo will be arrived at a destination safely.

The cargo is received the influence of the outside and it is likely to move by the force even if it was fixed. Due to the difficulty in predicting dynamic accelerations, 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.

To prevent transfer of cargo by the motion, we are securing the cargo with rope. But, the tension of securing rope might be changed by the external force, and the securing rope was acted on cyclic loading by hull motions. A number of serious accidents have 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.

In order to maintain the tension of rope and to prevent the cargo movement accidents, a lot of attention and checks are demanded not only while the loading/unloading and securing of cargoes but also under transportation because of the cyclic loading by ship motions. But it can be difficult to check the general condition and tension of rope in transport. 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. 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 Chapter, we carried out an experiment on using of the ship motion simulator for prediction of fluctuation tension of securing rope, and compare the prediction with the experiment of the fluctuation tension in case of the arbitrary frequency and initial tension using the data-base obtained through the experiments. Also, the results of prediction were verified through the experiment.

3.2 Process of prediction of fluctuation tension

Fig.1 shows a process of experiment and analyses to prediction of fluctuation tension by oscillation. 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. Next, it was compared the prediction with the experiment of the fluctuation tension by the motions. 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.

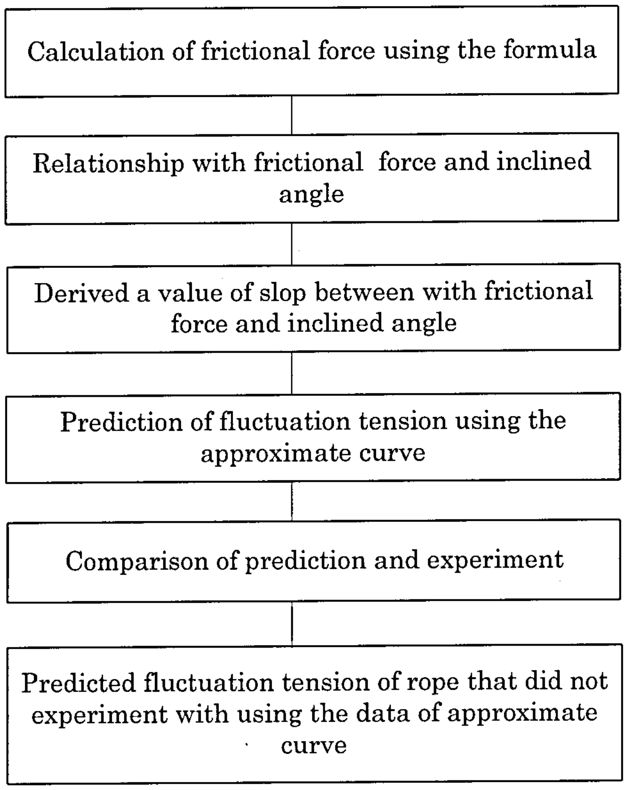


Figure 3- 1 Flow chart to prediction of fluctuation tension

3.3 Evaluation of forces acting on cargo units

Cargo taking into account the dynamic forces that may occur during sea transport and the most severe weather condition expected. Securing operations shall be completed before the ship leaves the berth and the securing should be based on the Cargo Securing Manual [1, 2].

Generally the forces which have to be taken by the securing devices are composed components acting relative to the axes of the ship, i.e. longitudinal, transverse and vertical direction [3], as shown in Chapter 2 (Table 2-2, 2-3 and Fig. 2-11).

3.3.1 Balance of forces

Figure 3-2 shows the forces acting on the object fixed on the roll and heave motions.

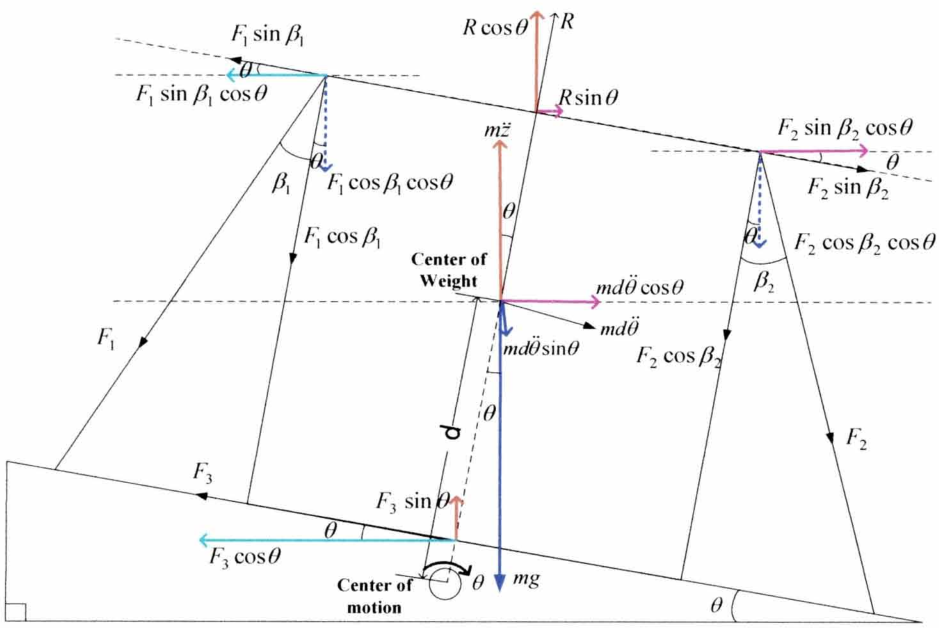


Figure 3- 2 Balance of forces acted on the securing cargo units by oscillation.

Where,

F_1, F_2 : Tension of rope

F_3 : Frictional force

β_1, β_2 : Angle between rope and fixed object

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

The balance of forces can be thought out the vertical direction and horizontal direction, as follows.

(a) Vertical direction

$$R\cos\theta + m\ddot{z} + F_3\sin\theta = mg + F_1\cos\beta_1\cos\theta + F_2\cos\beta_2\cos\theta + md\ddot{\theta}\sin\theta \quad (3\text{-}1)$$

(b) Horizontal direction

$$F_1\sin\beta_1\cos\theta + F_3\cos\theta = R\sin\theta + F_2\sin\beta_2\cos\theta + md\ddot{\theta}\cos\theta \quad (3\text{-}2)$$

According to numerical formula (3-1, 3-2), the drag and the frictional force of securing can be shown as follows.

(a) Drag Force (R)

$$R = \cos\theta(mg + F_1\cos\beta_1\cos\theta + F_2\cos\beta_2\cos\theta - m\ddot{z}) - \sin\theta(F_2\sin\beta_2\cos\theta - F_1\sin\beta_1\cos\theta) \quad (3\text{-}3)$$

(b) Frictional Force (F_3)

$$F_3 = \sin\theta(mg + F_1\cos\beta_1\cos\theta + F_2\cos\beta_2\cos\theta + md\ddot{\theta}\sin\theta - m\ddot{z}) + \cos\theta(F_2\sin\beta_2\cos\theta + md\ddot{\theta}\cos\theta - F_1\sin\beta_1\cos\theta) \quad (3\text{-}4)$$

3.3.2 Calculation of fluctuation tension

While the securing works in the field, the securing rope tension was not always equal, because of it is conducted by the personal experience. Moreover, the safety tension of cargo fixed with securing devices was checked and evaluated by the personal experience rather than quantitative methods.

In general, the total of the securing tension values of the securing devices on each side of a unit of cargo should be equal to the weight of the unit.

If an initial tension and the amount of the change of $F_1(F_2)$ are called $F_{01}(F_{02})$ and $\Delta F_1(\Delta F_2)$ respectively and $\beta_1 = \beta_2 = \beta$, $\Delta F_1 = \Delta F_2 = \Delta F$, $F_{01} = F_{02} = F_0$, (in formula (3-4), replace F_1, F_2 with $F_0 + \Delta F, F_0 - \Delta F$), the fluctuation tension is written as below.

$$\Delta F = \frac{1}{2\sin\beta\cos^2\theta}\left\{\sin\theta(mg + 2F_0\cos\beta\cos\theta - m\ddot{z}) - F_3 + md\ddot{\theta}\right\} \tag{3-5}$$

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 (3-4), the frictional force can be got simply because other factors are possible to measure.

3.4 Fluctuation tension of securing rope

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. If the fluctuation tension and residual tension of securing rope can be estimated exactly during transportation, it is helpful to prevent of accident, or to reduce of the cargo accidents happened by the insufficient securing through the selection of appropriate securing devices and checking.

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.

3.4.1 Condition of experiment

Figure 3-3, 3-4 shows a configuration of experimental apparatus, ship motion simulator, composed of steel box secured by rope and turnbuckle with load cell. The positive inclined angle of rolling motion is defined to the right side, as shown in Fig. 3-3.

The conditions of experiment, such as temperature and humidity, etc were recorded periodically, which are as following.

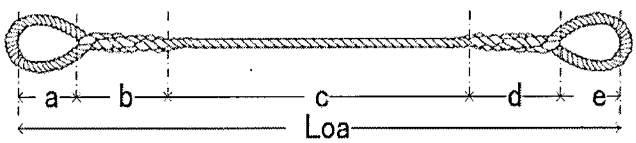
- Frequency of motion simulator(roll) : 0.1, 0.2, 0.3Hz
- Inclined angle of rolling : ± 5°, ± 10°

- 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*
- Temperature and Relative humidity: 18 ~ 22 ℃, 53 ~ 58 (%)

Table 3. 1 The general specification of rope

Type		a	b	c	d	e	Loa
Vinylon ϕ 12mm	Left side	67	58	95	40	62	322
	Right side	67	53	100	40	60	320
Vinylon ϕ 9mm	Left side	65	55	120	30	45	315
	Right side	65	47	128	30	42	312
Vinylon ϕ 6mm	Left side	40	35	165	30	32	302
	Right side	40	33	170	35	25	303
Cotton ϕ 9mm	Left side	55	40	127	38	40	300
	Right side	55	40	115	50	35	295

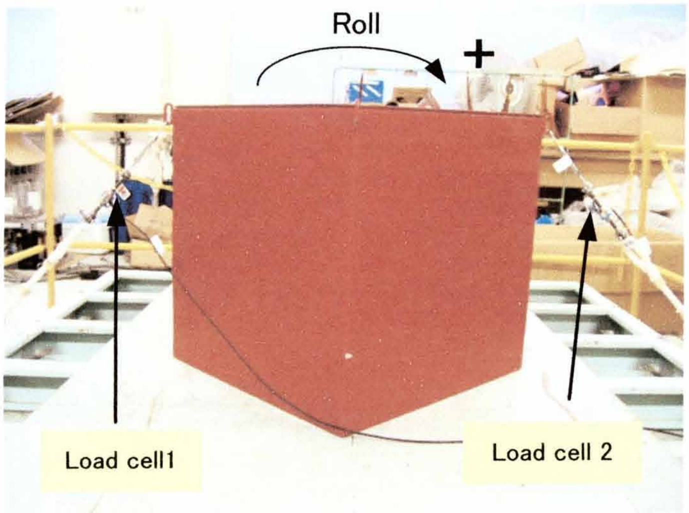
* Remarks : Left side - Load cell 1, Right side - Load cell 2



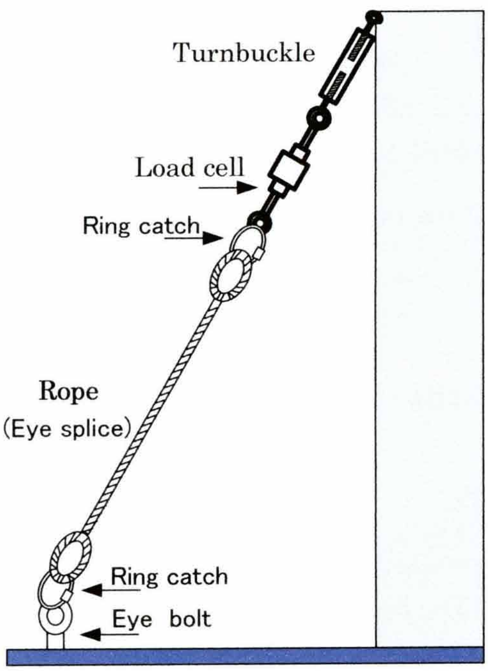
unit:(mm)

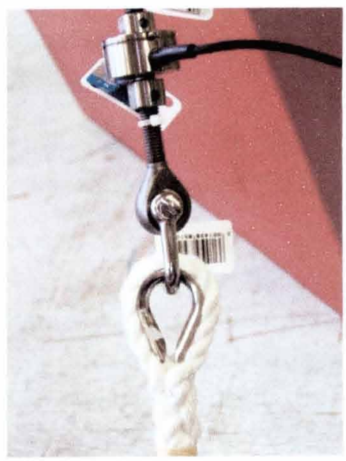
The experiment material was selected synthetic fiber and cotton ropes because it is often used securing of the cargo. An initial tension of rope set up respectively according to experimental conditions.

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 ± 15°, pitch ± 20°and heave 750mm.



< Set up on the motion simulator, front view >





(Combination of load cell and rope)

< Composition of box secured >

Figure 3- 3 Configuration of ship motion simulator

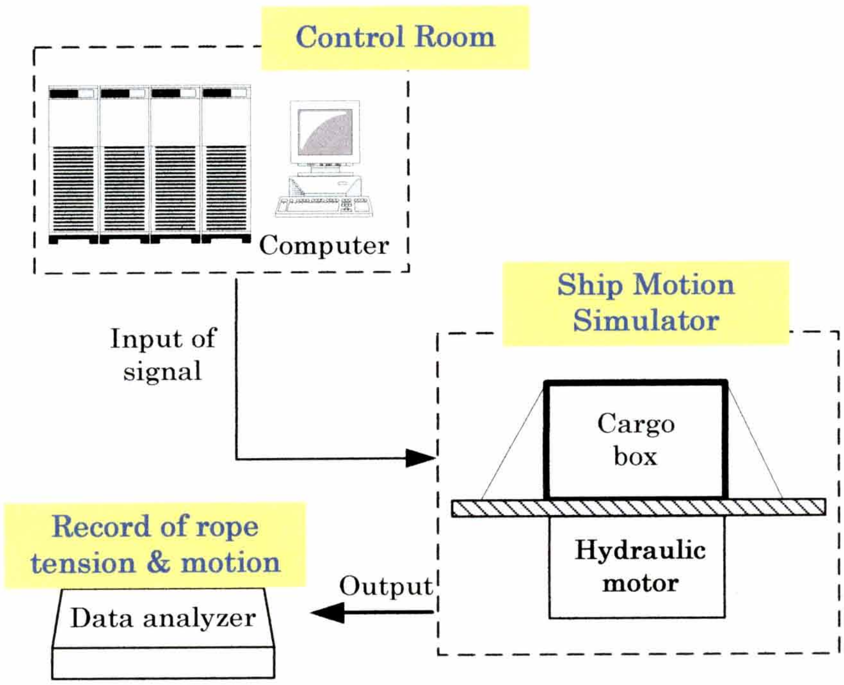


Figure 3- 4 Outline of experimental apparatus

3.4.2 Result of experiment

3.4.2.1 Frictional force by roll motion

Figure 3-5 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 of motion simulator(roll) : 0.2Hz
- Inclined angle of rolling : $\pm 10°$
- 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 (3-4). 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(dot line) was 46.9N as a result of calculation by formula(3-4).

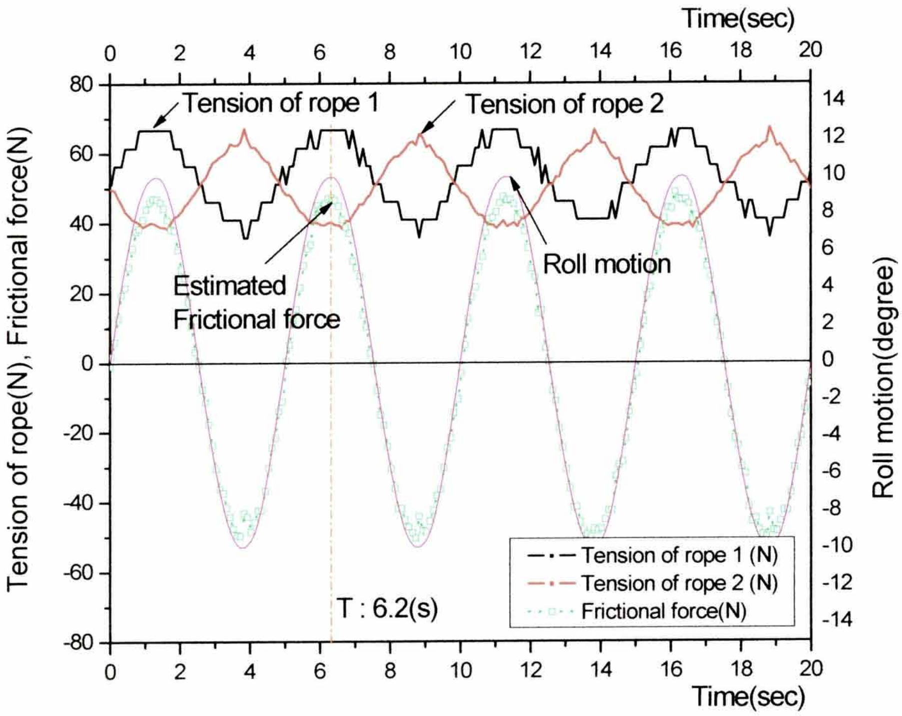


Figure 3- 5 Frictional force, tension by roll motion (Vinylon ϕ 9mm, f=0.2Hz)

3.4.2.2 Inclined angle and frictional force

Figure 3-6 was drawn by using Fig. 3-5. The horizontal axis is inclined angle and vertical axis is the frictional force and frictional force is absolute value.

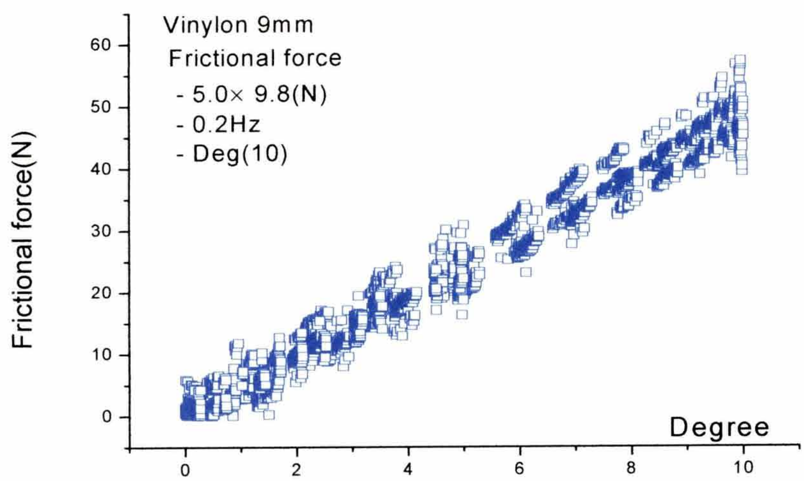


Figure 3- 6 Comparison to the inclined angle and frictional force

(Vinylon ϕ 9mm, f = 0.2Hz)

Look at the Fig. 3-6, frictional force have a tendency to straight line and can be obtainable an 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. 3-7 ~ 3-19), inclined angle and frictional force had a tendency to straight line as like Fig. 3-6.

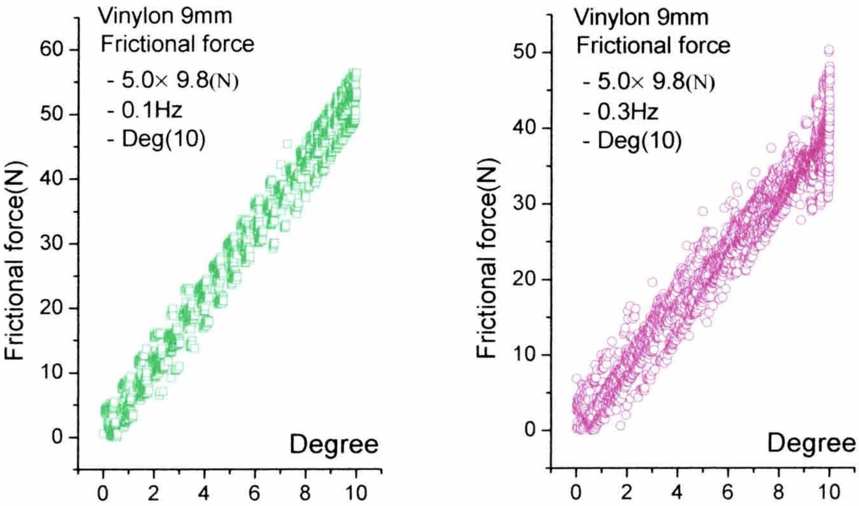


Figure 3- 7 Comparison to the inclined angle and frictional force (a)
(Vinylon ϕ 9mm, f = 0.1, 0.3Hz)

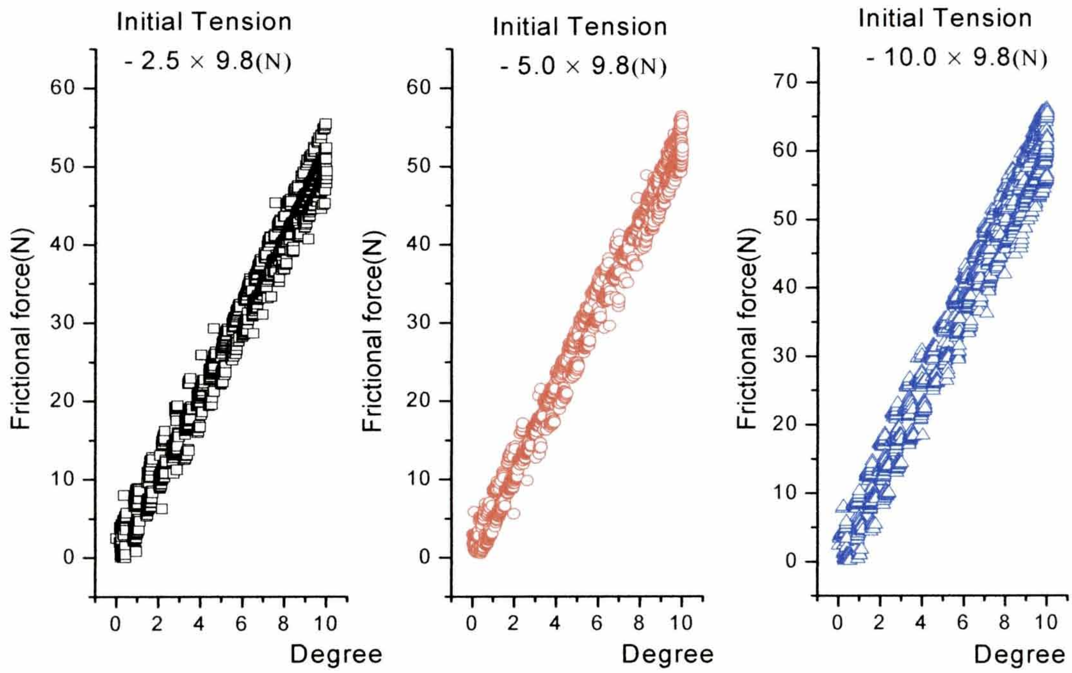


Figure 3- 8 Comparison to the inclined angle and frictional force (b)
(Vinylon ϕ 12mm, f = 0.1Hz)

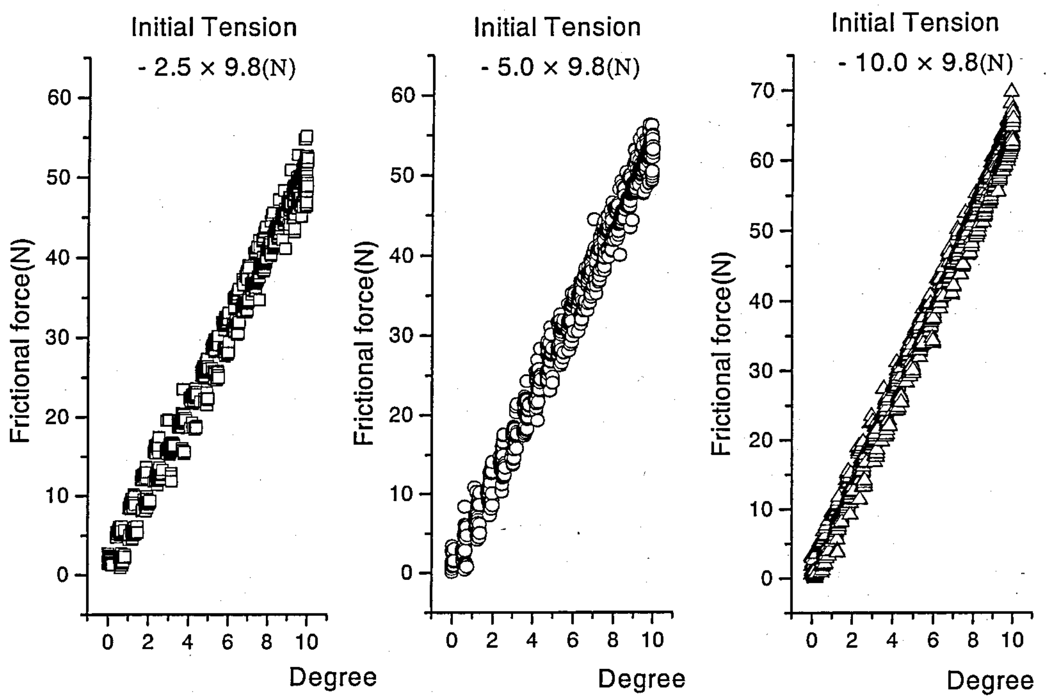


Figure 3- 9 Comparison to the inclined angle and frictional force (c)
(Vinylon ϕ 6mm, f = 0.1Hz)

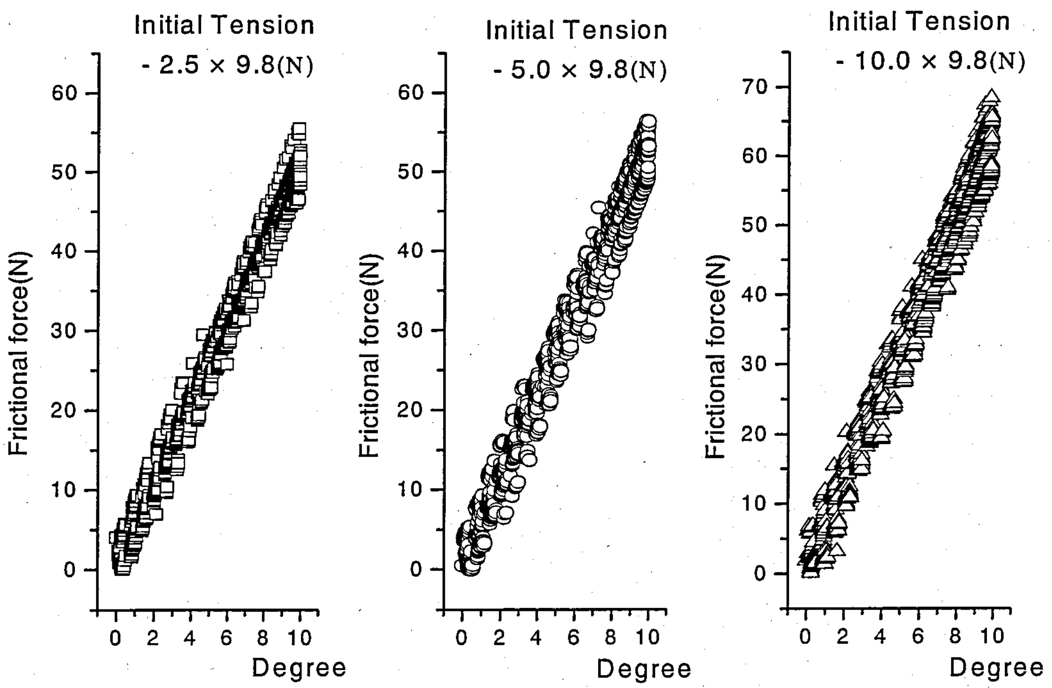


Figure 3- 10 Comparison to the inclined angle and frictional force (d)
(Vinylon ϕ 9mm, f = 0.1Hz)

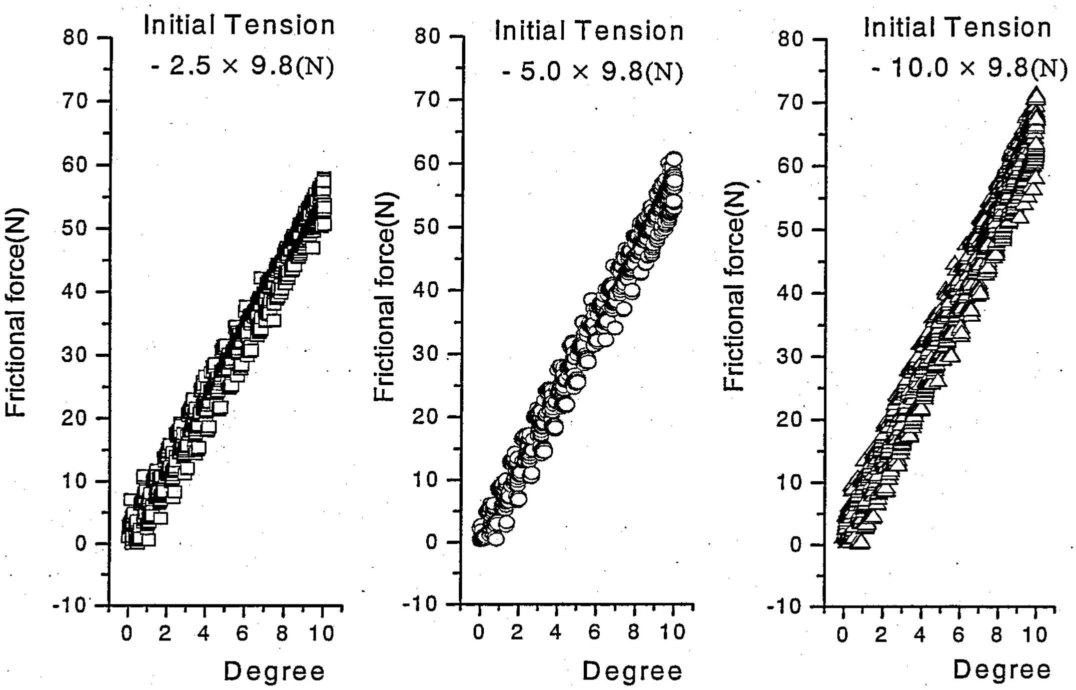


Figure 3- 11 Comparison to the inclined angle and frictional force (e)
(Cotton ϕ 9mm, f = 0.1Hz)

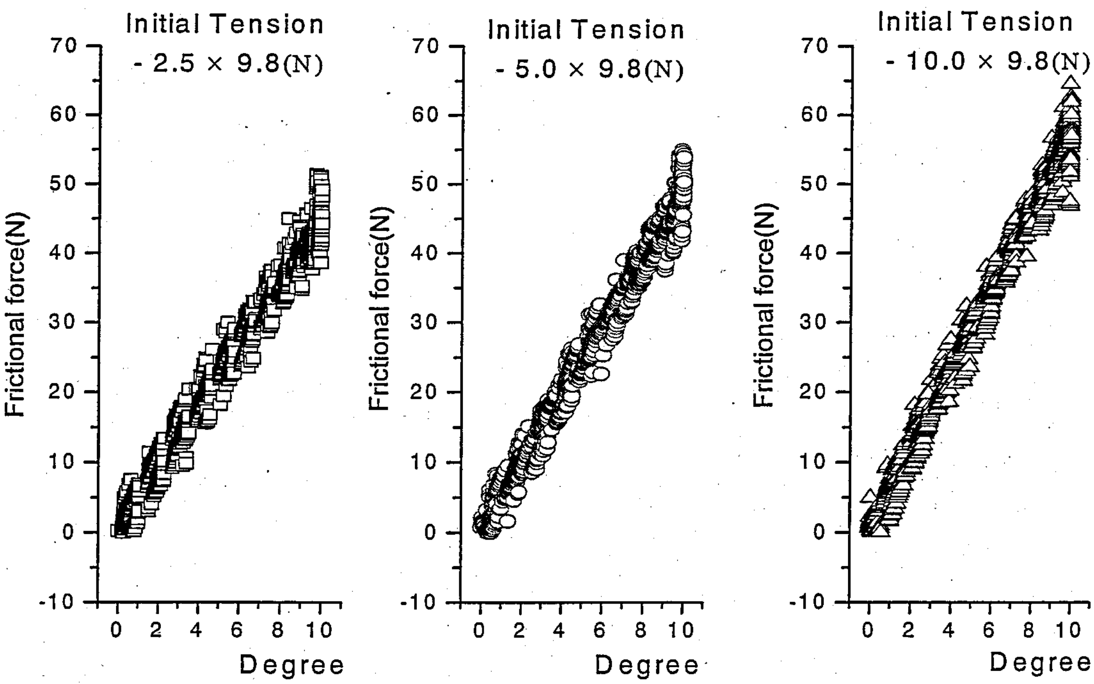


Figure 3- 12 Comparison to the inclined angle and frictional force (f)
(Vinylon ϕ 12mm, f = 0.2Hz)

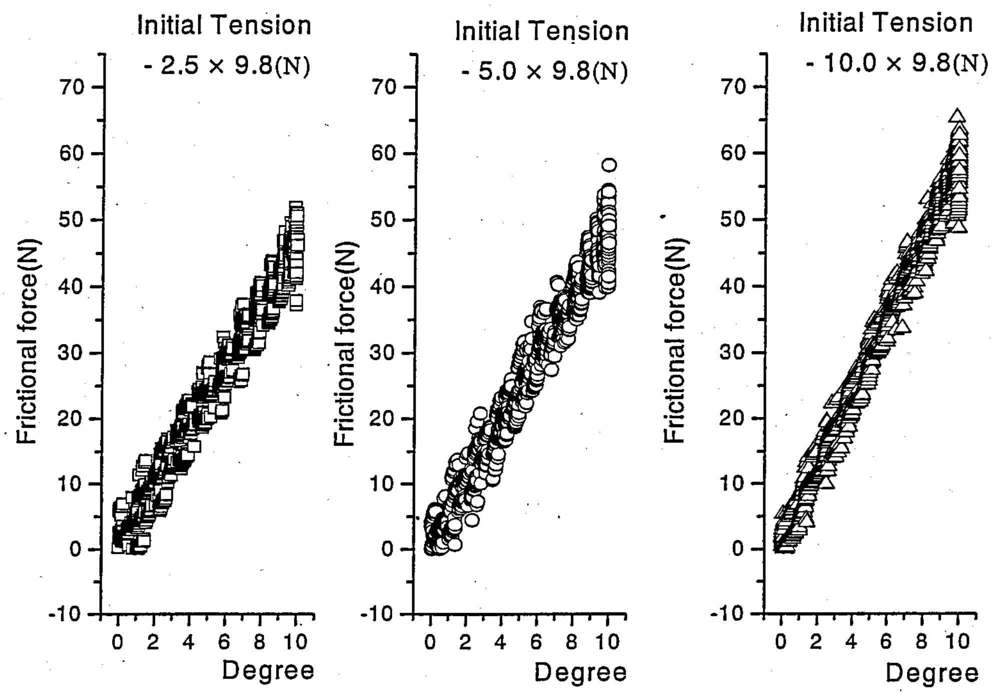


Figure 3- 13 Comparison to the inclined angle and frictional force (g)
(Vinylon ϕ 6mm, f = 0.2Hz)

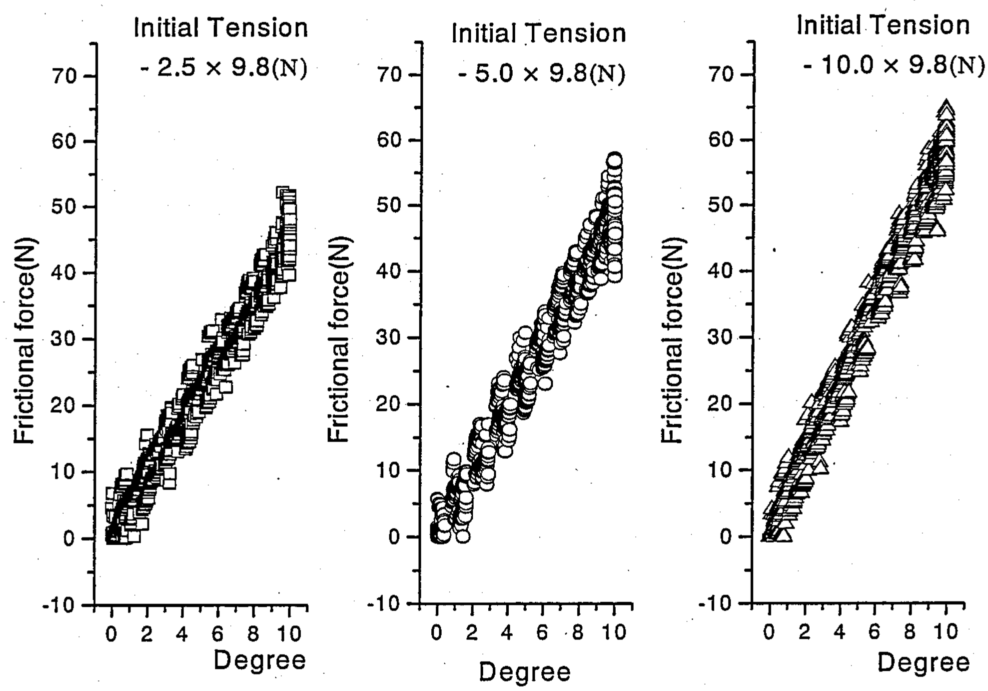


Figure 3- 14 Comparison to the inclined angle and frictional force (h)
(Vinylon ϕ 9mm, f = 0.2Hz)

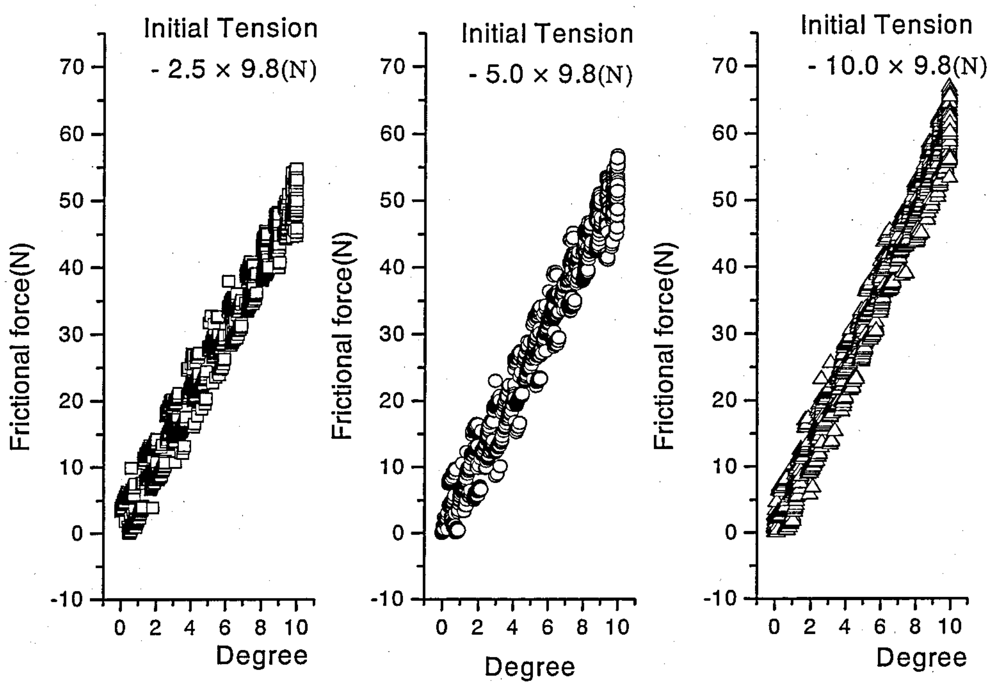


Figure 3- 15 Comparison to the inclined angle and frictional force (i)
(Cotton ϕ 9mm, f = 0.2Hz)

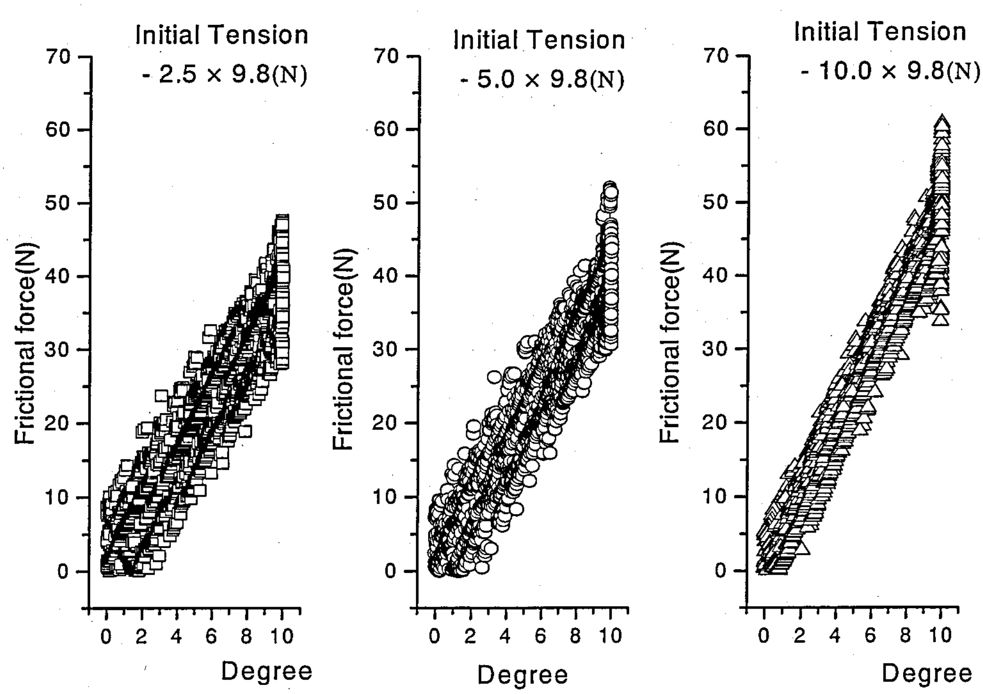


Figure 3- 16 Comparison to the inclined angle and frictional force (j)
(Vinylon ϕ 12mm, f = 0.3Hz)

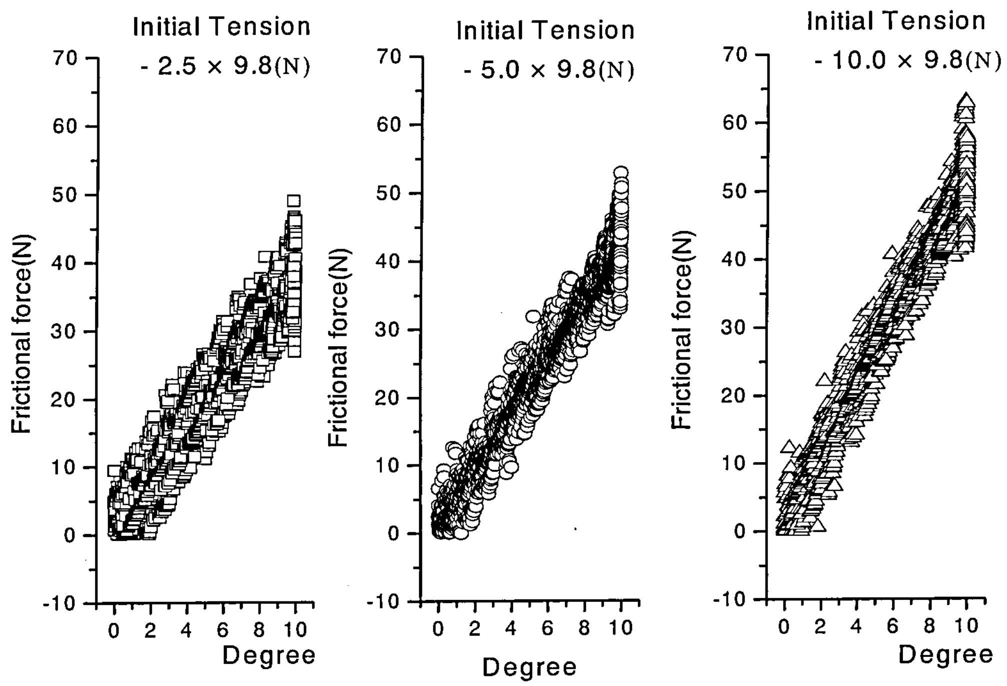


Figure 3- 17 Comparison to the inclined angle and frictional force (k)
(Vinylon ϕ 6mm, f = 0.3Hz)

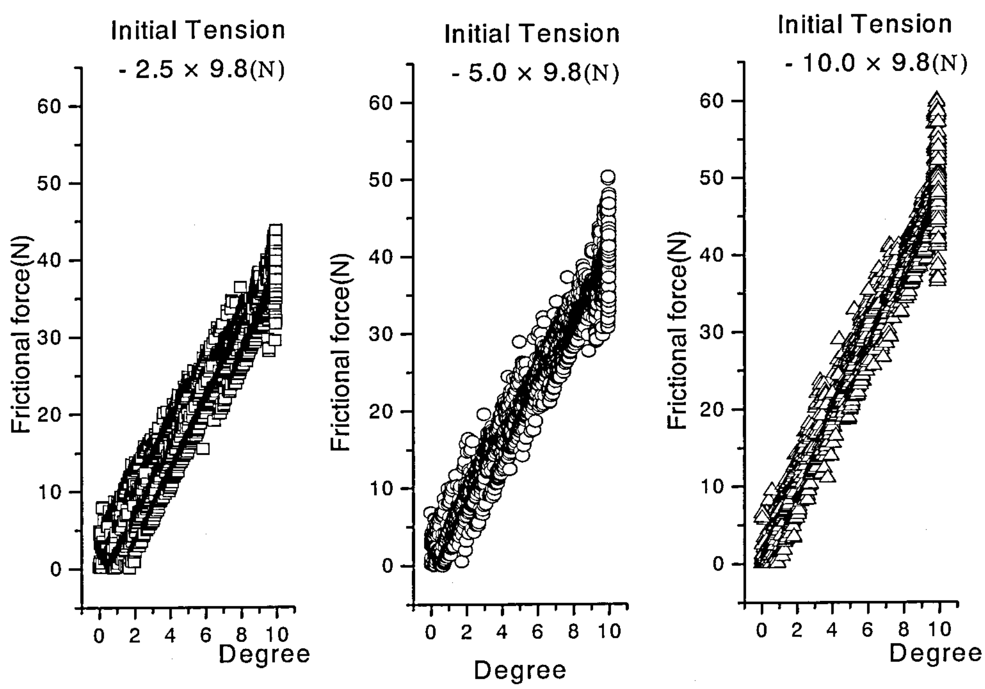


Figure 3- 18 Comparison to the inclined angle and frictional force (l)
(Vinylon ϕ 9mm, f = 0.3Hz)

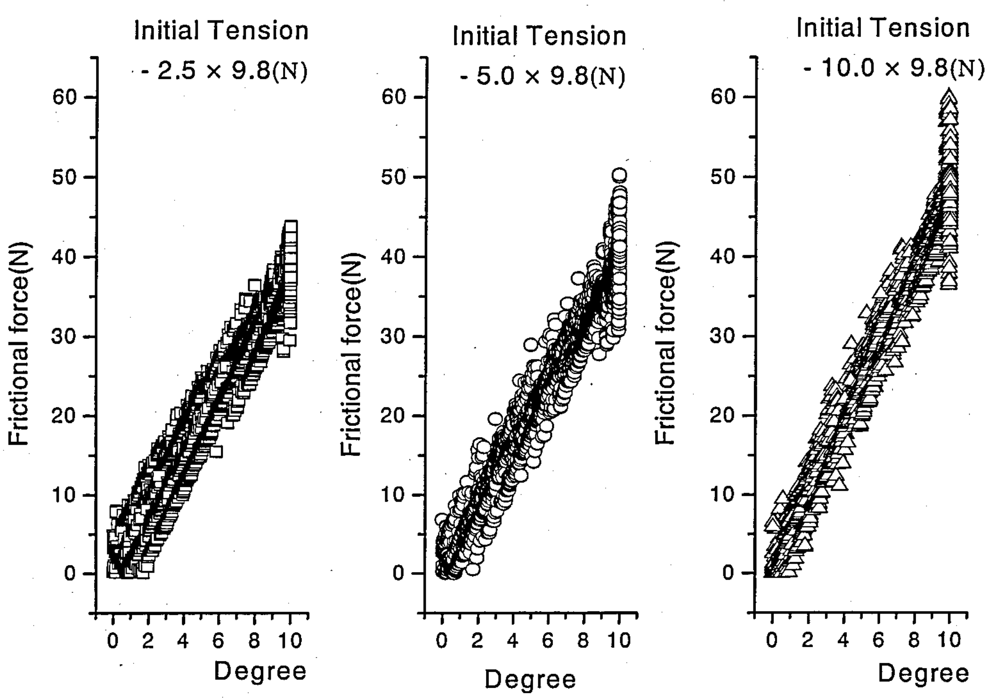


Figure 3- 19 Comparison to the inclined angle and frictional force (m)
(Cotton ϕ 9mm, f = 0.3Hz)

3.4.2.3 Approximate curve

We can derive a slope of Vinylon 9mm rope from the inclined angle and frictional force (Fig.3-5, 3-6) 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 frictional force was calculated by the frictional force formula (3-4). 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 Figure 3-20 by using the same method when an initial tension is 2.5, 10.0 × 9.8N.

Fig. 3-20 ~ 3-23 shows an approximate curve in the case of initial tension of Vinylon

12, 9, 6 mm and Cotton 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.

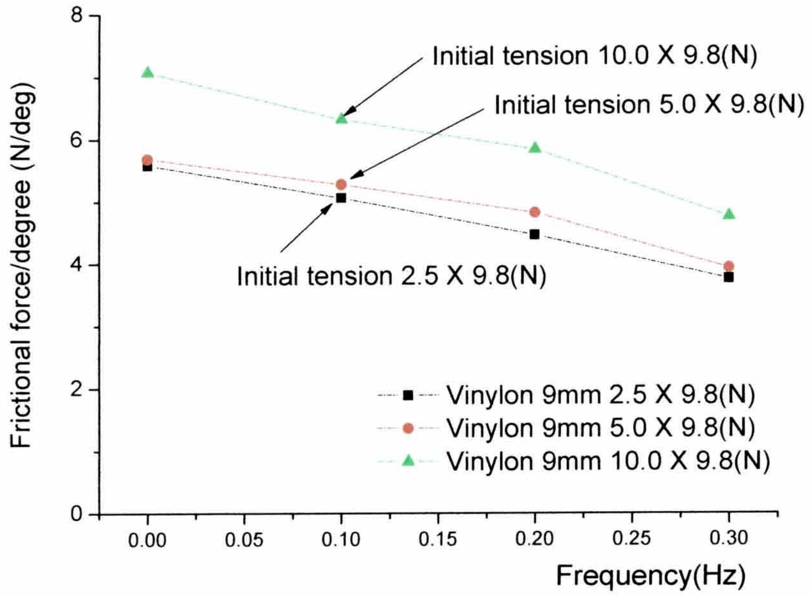


Figure 3- 20 Comparison between frictional force/ degree and frequency (a)
(Vinylon ϕ 9mm)

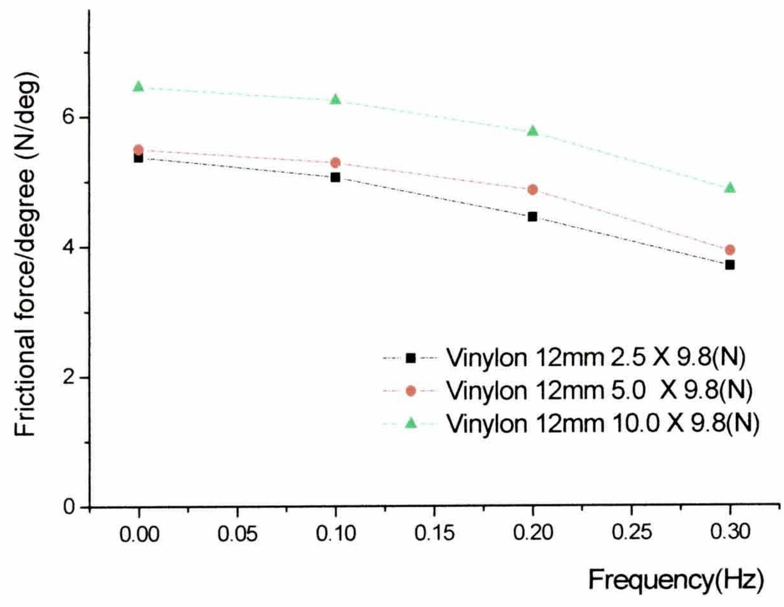


Figure 3- 21 Comparison between frictional force/ degree and frequency (b)
(Vinylon ϕ 12mm)

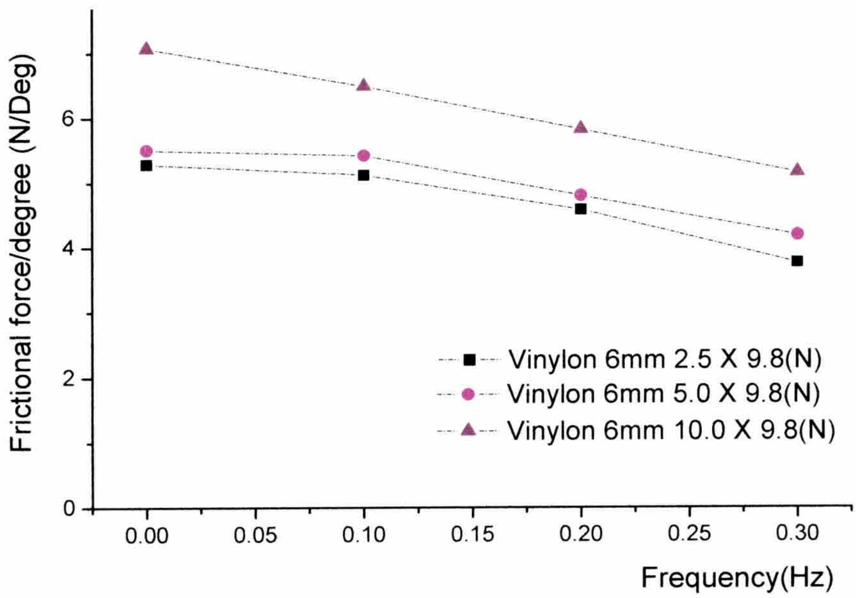


Figure 3- 22 Comparison between frictional force/ degree and frequency (c)
(Vinylon ϕ 6mm)

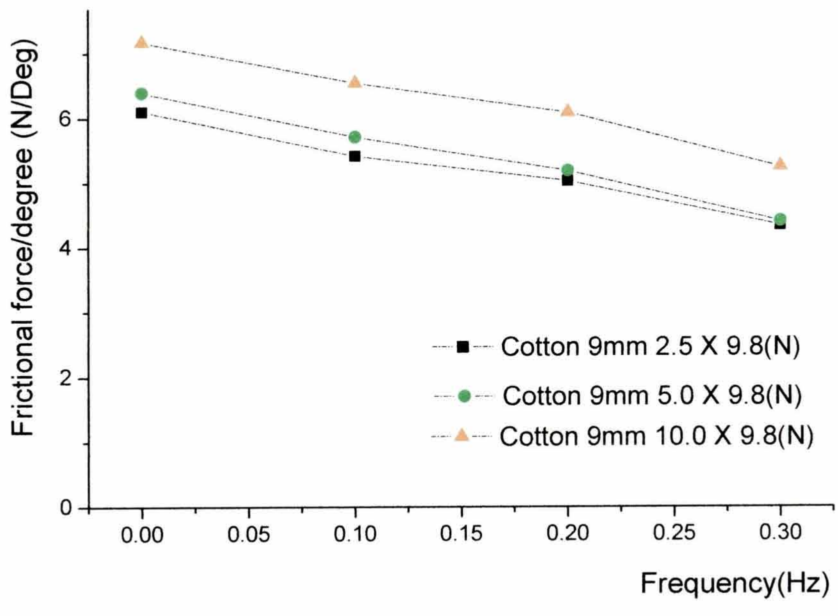


Figure 3- 23 Comparison between frictional force/ degree and frequency (d)
(Cotton ϕ 9mm)

3.4.2.4 Prediction of fluctuation tension

Using the Fig.3-20 ~ 3-23 data, we try to prediction of fluctuation tension frequency on which it doesn't experiment. Firstly, we calculated fluctuation tension by formula (3-5) 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 (3-5). 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 Hz, too.

Figure 3-24 ~ 3-27 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. 3-24 ~ 3-27, 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.

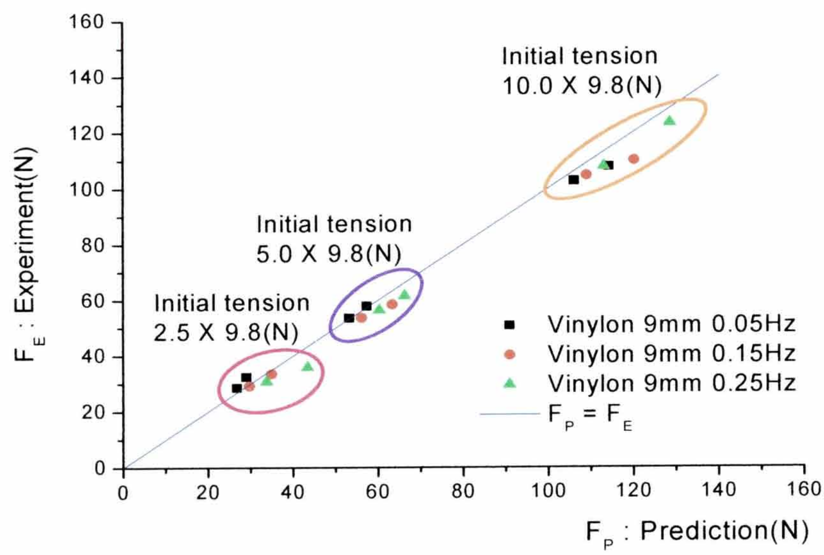


Figure 3- 24 Comparison of Prediction and Experiment (a)
(Vinylon ϕ 9mm)

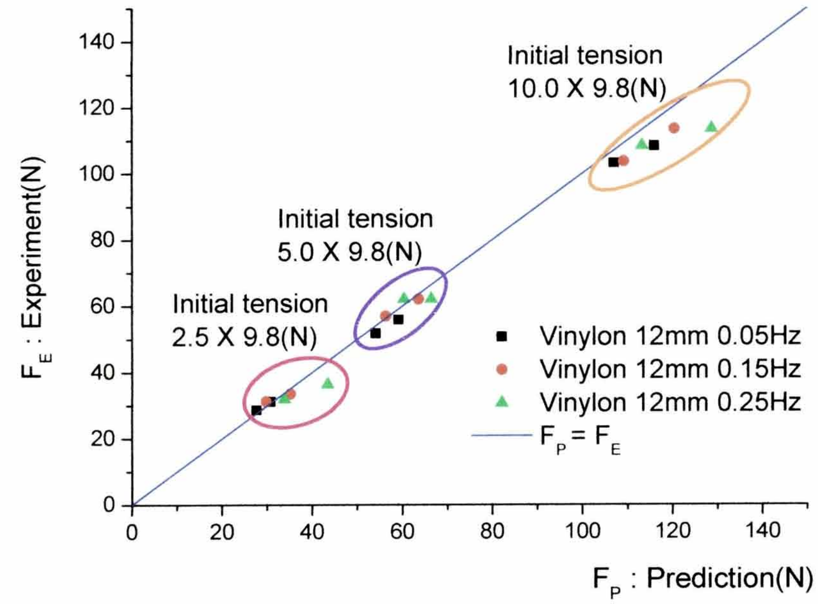


Figure 3- 25 Comparison of Prediction and Experiment (b)

(Vinylon ϕ 12mm)

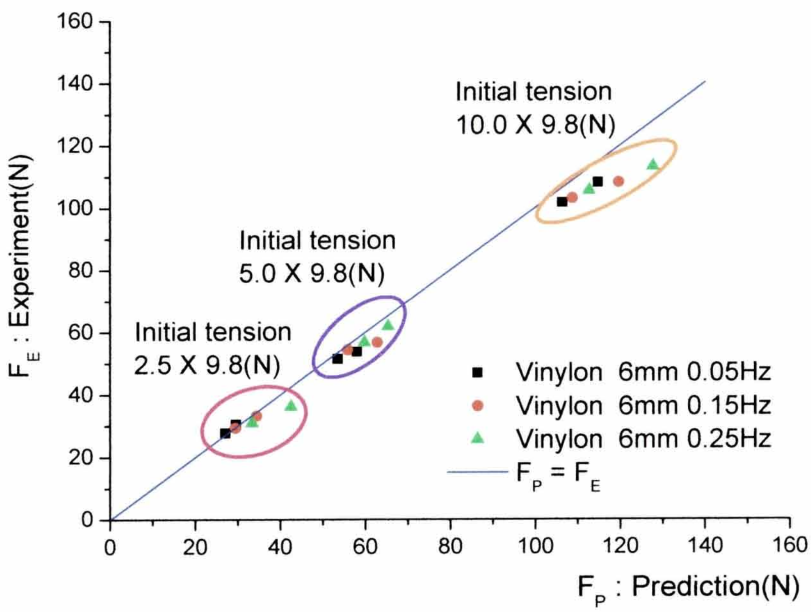


Figure 3- 26 Comparison of Prediction and Experiment (c)

(Vinylon ϕ 6mm)

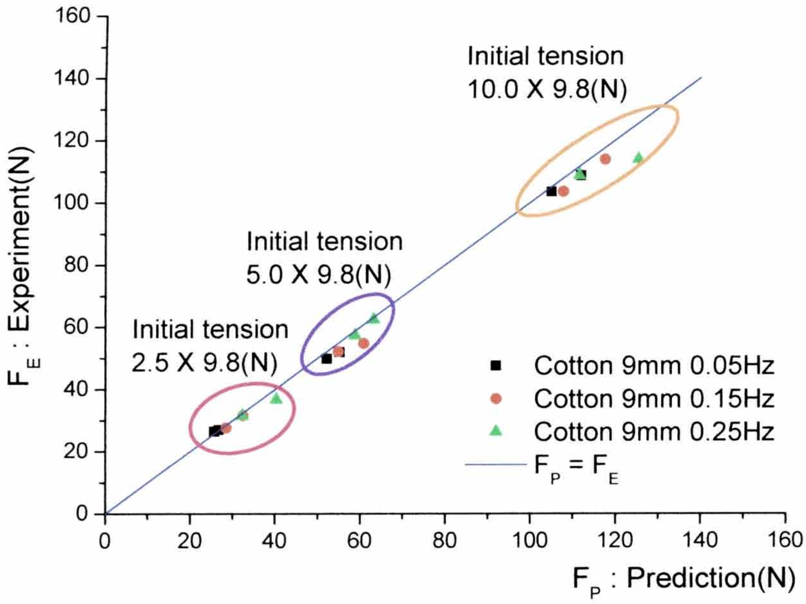


Figure 3- 27 Comparison of Prediction and Experiment (d)
(Cotton ϕ 9mm)

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.

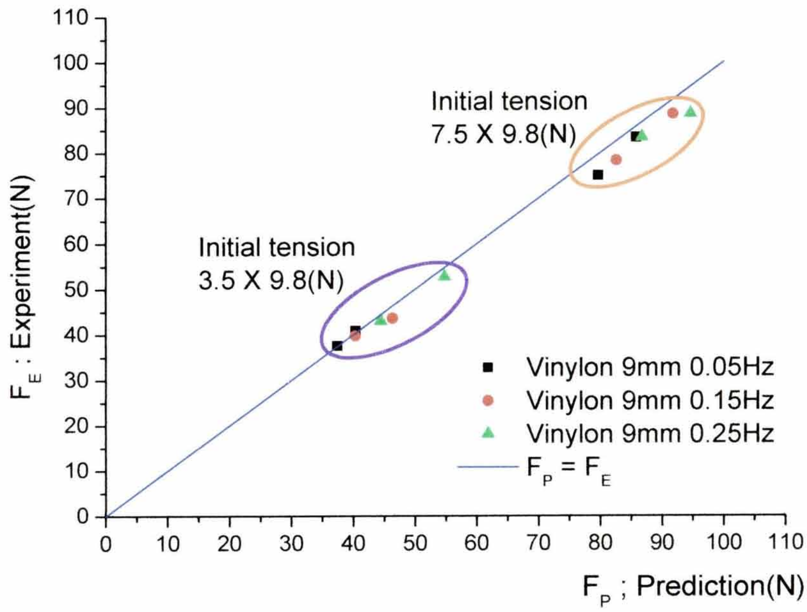


Figure 3- 28 Comparison of Prediction and Experiment (a)
(Vinylon ϕ 9mm)

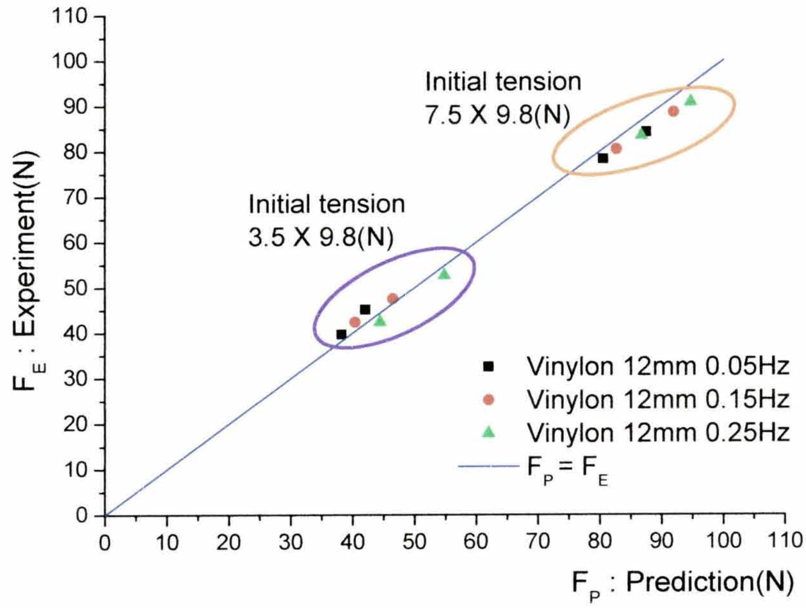


Figure 3- 29 Comparison of Prediction and Experiment (b)
(Vinylon ϕ 12mm)

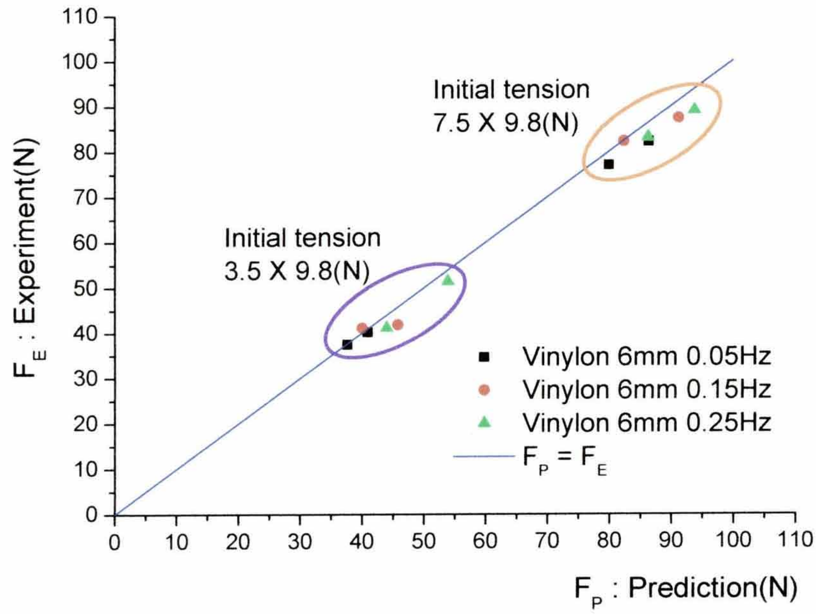


Figure 3- 30 Comparison of Prediction and Experiment (c)
(Vinylon ϕ 6mm)

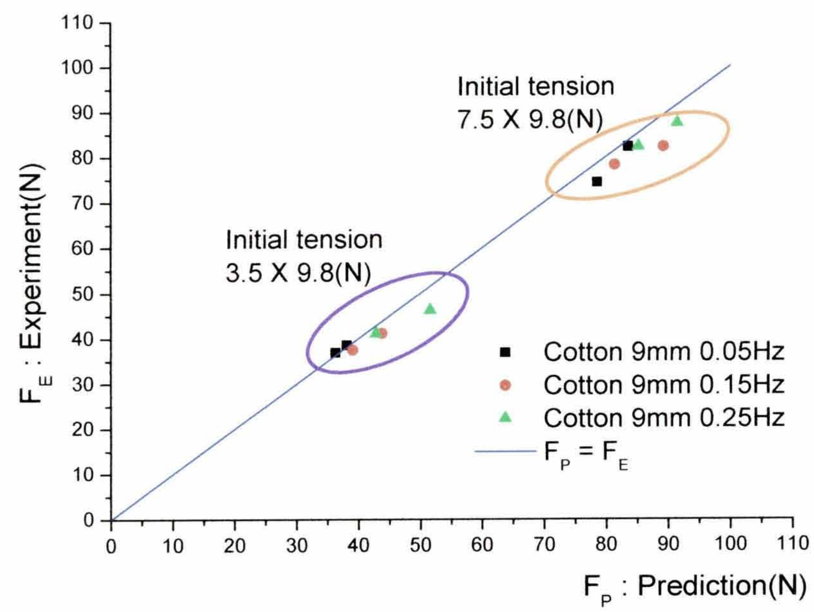


Figure 3- 31 Comparison of Prediction and Experiment (d)
(Cotton ϕ 9mm)

Using the data of Fig. 3-28 ~ 3-31, Table 3.2 shows the comparison of prediction and the experimental result. A percentage of accuracy to the gap between prediction and experimental result is defined as below.

$$PE_P(\%) = \frac{(\text{Prediction - Experiment})}{\text{Experiment}} \times 100 \tag{3-6}$$

It can be seen from Table 3.2 that the prediction and experiment is almost corresponding in such a case of any initial tension and frequency

Table 3. 2 Comparison of prediction and experimental

Frequency (Hz)	Amplitude of oscillation (deg)	Initial tension (×9.8(N))	Type of rope and diameter($PE_P(\%)$)			
			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

3.5 Conclusion

In this Chapter, 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 measured a change of rope tension by oscillation using ship motion simulator. As a result of experiment, we confirmed that extend of the changing a tension of rope according to change a frequency of motion and type of rope.

(2) For the prediction of the fluctuation tension of securing rope, in this time, we thought only rolling motion. The frictional force can be got by the formula (3-4) simply.

(3) We derived mathematical equations to calculate of the fluctuation tension acted on the securing cargo units by oscillation (formula (3-5)).

(4) The approximation straight line displayed to through compare of the relations between the inclined angle and frictional 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.

(5) 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.

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.

References

(1) IMO (2003), "The Code of Safe Practice for Cargo Stowage and Securing", pp. 1-15.
(2) IMO (1997), "Guidelines for the Preparation of the Cargo Securing Manual", pp. 1 - 9.
(3) DNV (2004), "Cargo Securing Model Manual", pp. 13-19.

Chapter 4 Prediction of Residual Tension of Securing Rope

4.1 Prologue

In the previous Chapter 3, it was confirmed that the fluctuation tension of securing rope by oscillation could be predicted (1).

A general rule is that how to calculate number and strength of securing devices required carried out according to Annex 13 to the CSS Code. The assumption of external forces act on securing devices is derived from maximum acceleration of the cargo due to the ship motions. But, the cyclic loading usually makes securing rope oscillate under the navigation. Therefore, the 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 (2 ~ 6), 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.

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. On the contrary, improper stowage and securing of cargo will be potentially hazardous to the securing of other cargoes, persons onboard and the ship itself.

In this Chapter, 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 in the estimated fluctuation tension, and their residual tensions were compared with each other.

4.2 Residual tension of securing rope

When the fluctuation tension acts on the securing rope by the ship motions, the residual tension is decreased little by little, and decreasing rate is faster than it without the tension fluctuating.

Figure 4-1 shows a process of experiment and analyses to prediction of residual tension by oscillation.

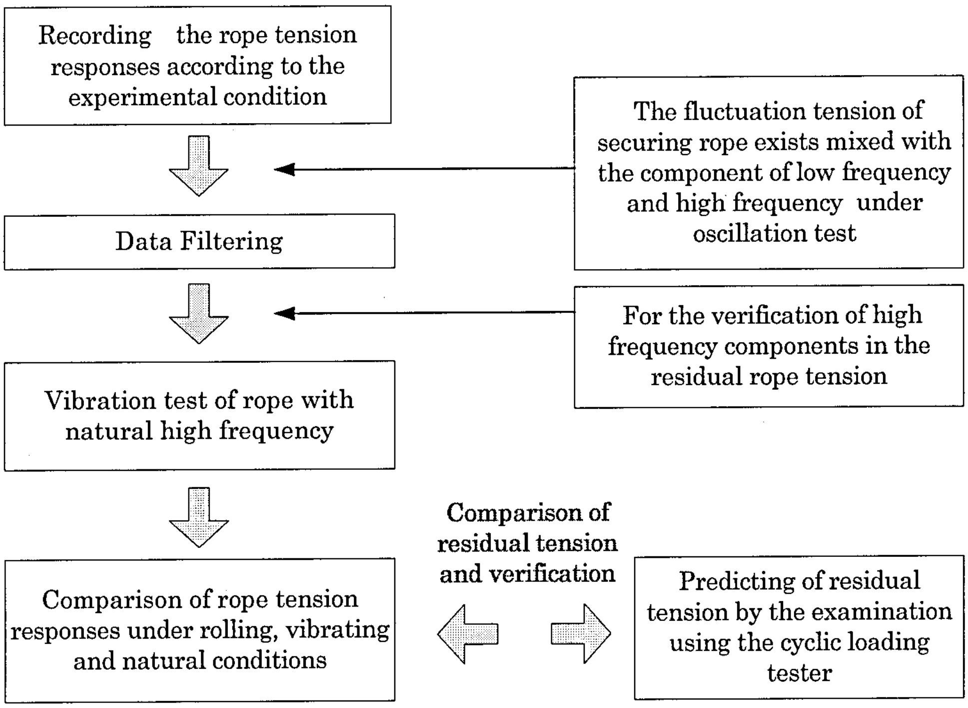


Figure 4- 1 Flow chart to prediction of residual tension

4.2.1 Oscillation test

4.2.1.1 Condition of experiment

The configuration of oscillation test was shown in Chapter 3 (Fig. 3-3); the ship motion simulator, composed of steel box secured by rope and turnbuckle with load cell (KYOWA-LUR-A-SA1), and the positive inclined angle of rolling motion is defined to the right side.

Test conditions, such as temperature and humidity, etc. were recorded periodically, which are as following.

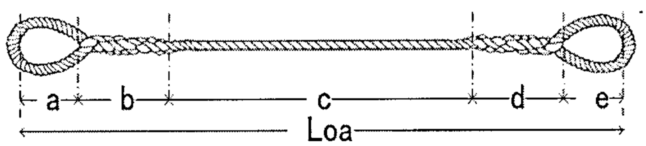
- Frequency of motion simulator (roll) : 0.3Hz
- Initial rope tension : 49N
- Inclined angle of rolling : ± 10 °
- Sampling rate of data recording : 100Hz

- Type and Diameter of rope : Cotton, ϕ 3mm
- Recording duration and interval time : 1 and 5 minutes
- Temperature and Relative humidity : 26.5 ~ 28.5℃, 58 ~ 63(%)

Table 4. 1 The general specification of rope

Type		a	b	c	d	e	Loa
Rolling motion	Left side (LD-1)	30	35	145	35	30	275
	Right side(LD-2)	30	30	155	30	30	275
Simple extension	Left side (LD-1)	30	25	170	25	25	275
	Right side(LD-2)	35	25	165	25	30	280

* Remarks : Left side - Load cell 1, Right side - Load cell 2



unit:(mm)

4.2.1.2 Result and analysis

Figure 4-2 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. 4-2 that the rope tension is changed according to the roll motions and especially is fluctuated with high frequency at inclined angle change.

Fig. 4-3(a) and (b) show its low-pass and high-pass filtering results using the 2nd order Bessel filter, respectively.

Fig. 4-4 shows low-pass filtering result between the elapsed time 23h 59m25s ~ 23h59m35s and dot line of residual tension (about 25N).

The residual rope tension by oscillation test was obtained by the arithmetical mean of recorded data for 1 minute using low-pass filtering.

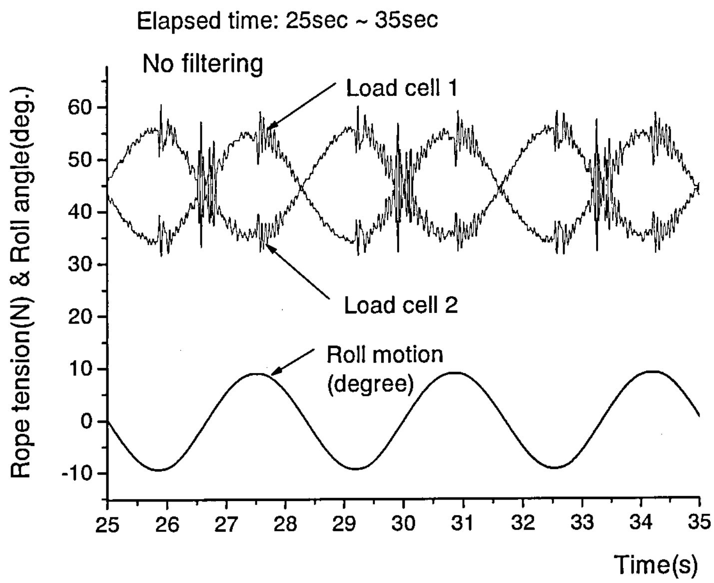


Figure 4- 2 Rope tension responses according to rolling motion

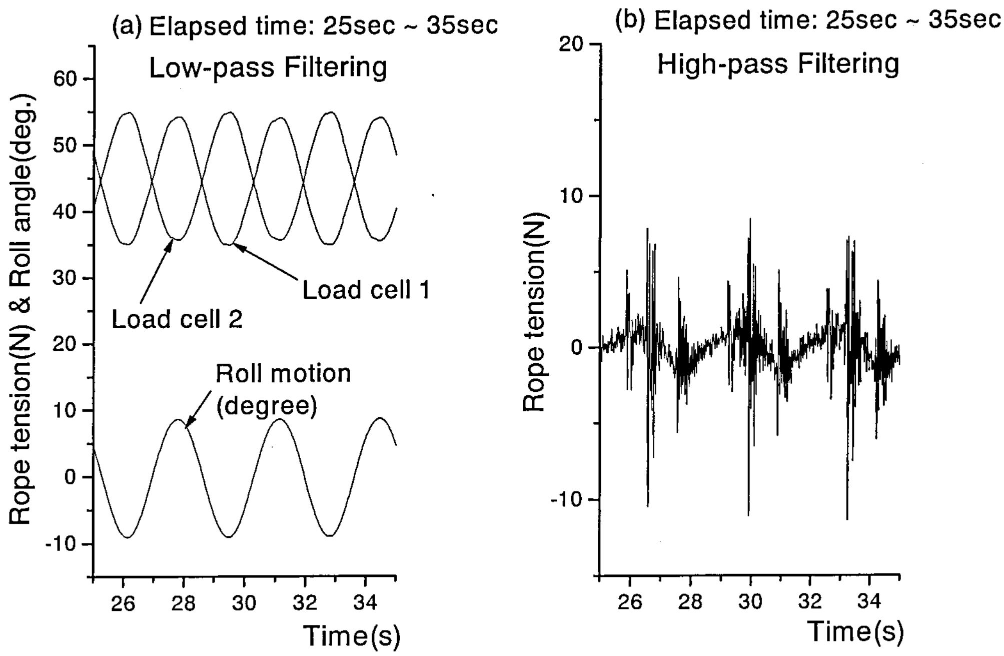


Figure 4- 3 Filtering results of rope tension responses
(Low-pass and High-pass filter, 2nd order Bessel filter)

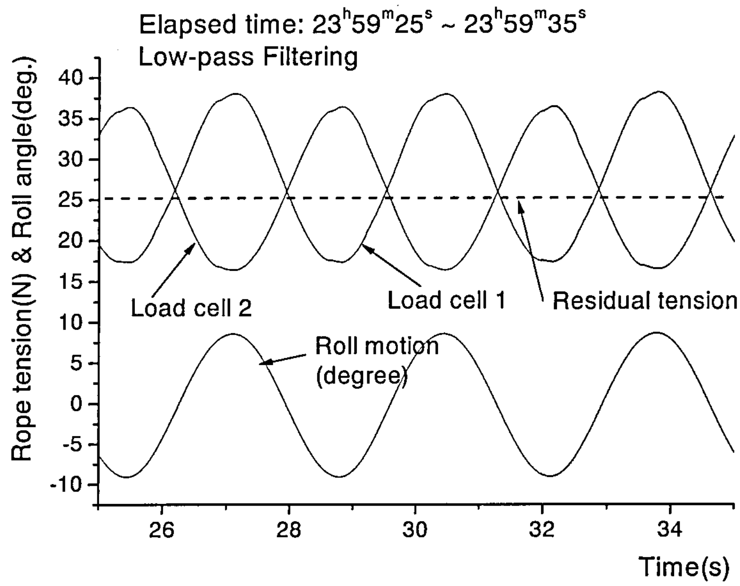


Figure 4- 4 Low-pass filtering result (2nd order Bessel filter)

Figure 4-5 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 of symbol △ shows the creep deformation. Creep is the tendency of solid material to slowly move or deform permanently under the influences of stresses, for example tensile forces, compressive forces, shear, bending or twisting. It occurs as a result of long term exposure to levels of stress that are below the yield strength of the material. The rate of this deformation is a function of the material properties, exposure time, exposure temperature and the applied structural load. In the initial stage, the strain rate is relatively high, but slows with increasing strain. This is due to work hardening. The strain rate eventually reaches a minimum and becomes near constant. This is due to the balance between work hardening and annealing. This stage is known as steady-state creep. As deformation occurs, internal inter-molecular forces arise which oppose the applied force. If the applied force is not too large these forces may be sufficient to completely resist the applied force, allowing the object to assume a new equilibrium state and to its original state when the load is removed. A larger applied force may lead to a permanent deformation of the object or even to its structural failure.

The rope tension became about 36N at natural condition from the initial tension 49N, but it dropped to about 25N under rolling condition after 24 hours. The securing rope tension was decreased naturally without any external factors because of the creep deformation behavior of rope. It could be found, however, that the residual tension of securing rope would be decreased much more under the rolling motion.

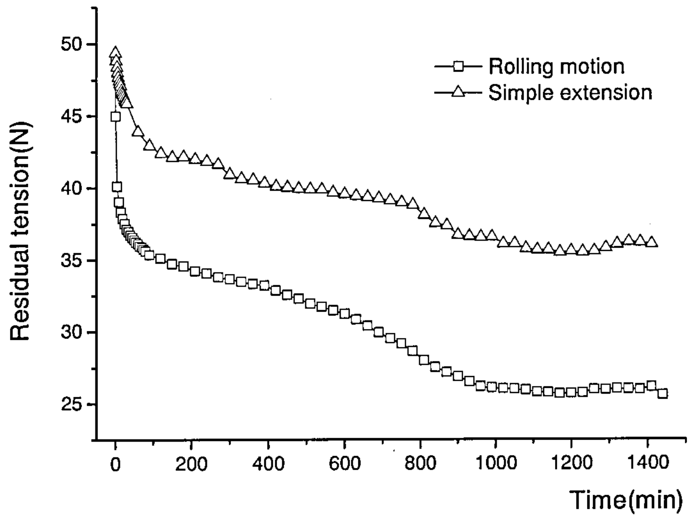


Figure 4- 5 Rope tension responses under rolling and natural conditions

4.2.2 Vibration test

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. 4.2 ~ 4.3(a, b), 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.

4.2.2.1 Sinusoidal sweep test

Figure 4-6 illustrates a process of sinusoidal sweep test to check the resonance frequency and the change of rope tension, and sinusoidal vibration tests were carried out based on JIS Z 0232 [7].

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.

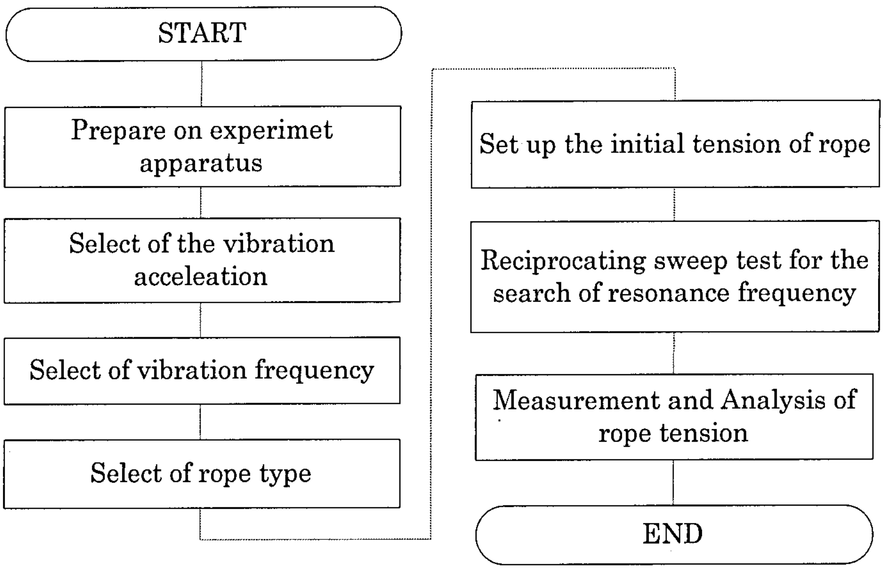


Figure 4- 6 Flow chart of vibration test

Figure 4-7 shows the configuration of vibration simulator with steel box fixed on the vibration table using the turnbuckle, shackle, load cell and rope.

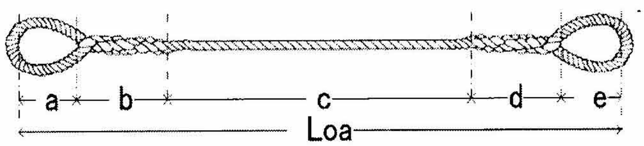
The conditions of vibration test are as following.

- 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
- Temperature and Relative humidity : 26 ~ 31℃, 53 ~ 60(%)

Table 4. 2 The general specification of rope

Type			a	b	c	d	e	Loa(mm)
Sinusoidal sweep test	420(s)	LD-1	30	30	165	25	30	280
		LD-2	30	28	162	30	30	280
	600(s)	LD-1	30	30	170	30	30	290
		LD-2	35	25	175	30	35	300
	900(s)	LD-1	30	25	162	28	30	275
		LD-2	30	28	157	30	30	275
	1800(s)	LD-1	30	25	165	25	30	275
		LD-2	30	25	170	25	30	280

* Remarks : Left side - Load cell 1(LD-1), Right side - Load cell 2(LD-2)



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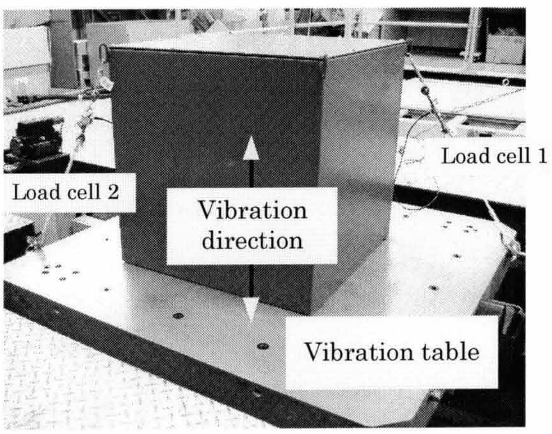


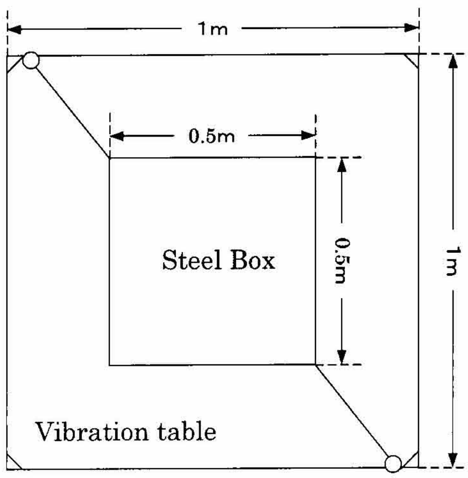


Figure 4- 7 Configuration of vibration simulator

Figure 4-8 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. 4-3(b), could be smaller than that at the resonance frequency by the vibrating.

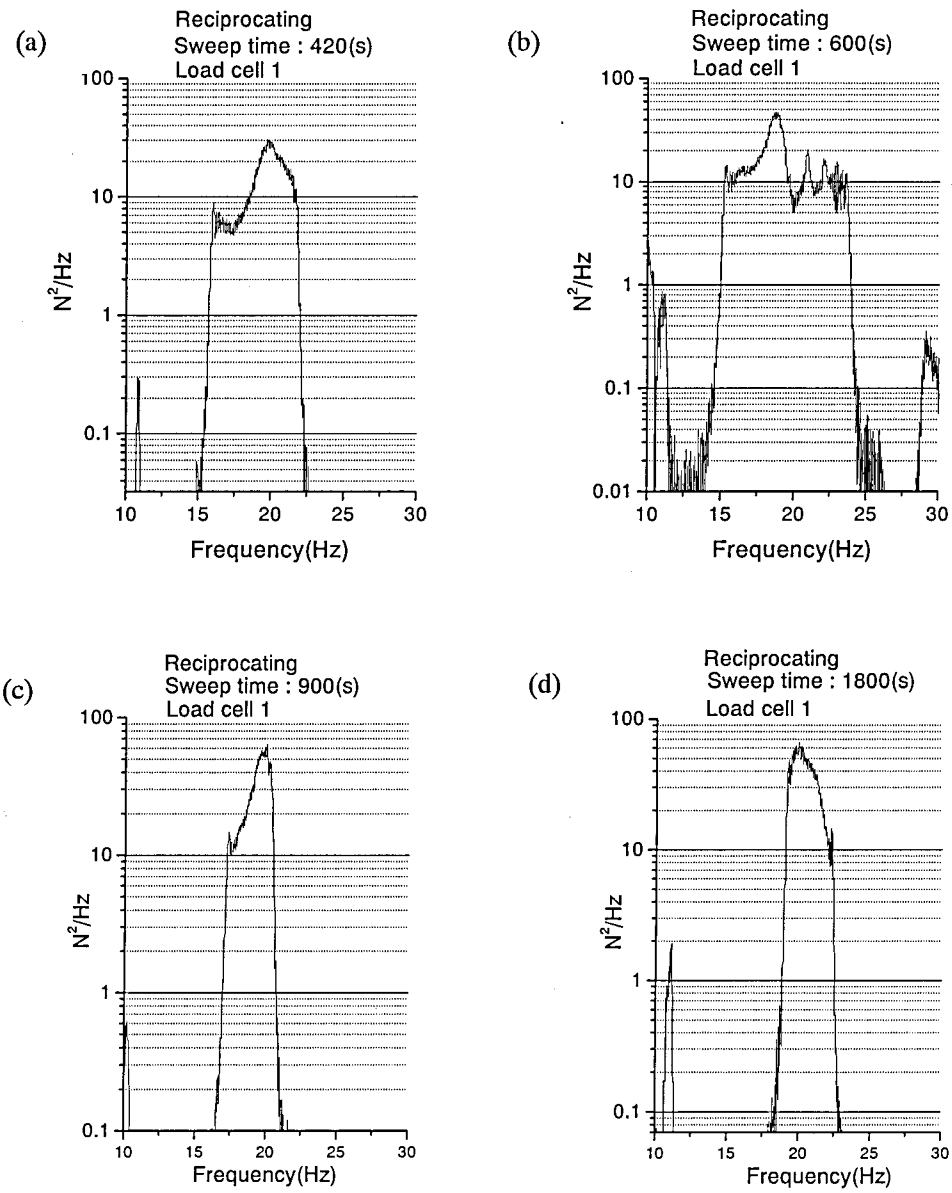


Figure 4- 8 PSD chart of vibration tension in the sweep tests

4.2.2.2 Vibration test in natural frequency

As shown in Fig. 4-8, 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

Table 4. 3 The general specification of rope

Type		a	b	c	d	e	Loa(mm)
Rope – Cotton, ϕ 3mm	LD-1	35	30	155	30	30	280
	LD-2	30	30	155	35	30	280

Figure 4-9 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. 4-3(b).

Figure 4-10 illustrates the rope tension response under rolling, vibrating and natural conditions. The rope tension by vibration test was calculated by the arithmetical mean of recording data for 1 minute (number of data: 6000).

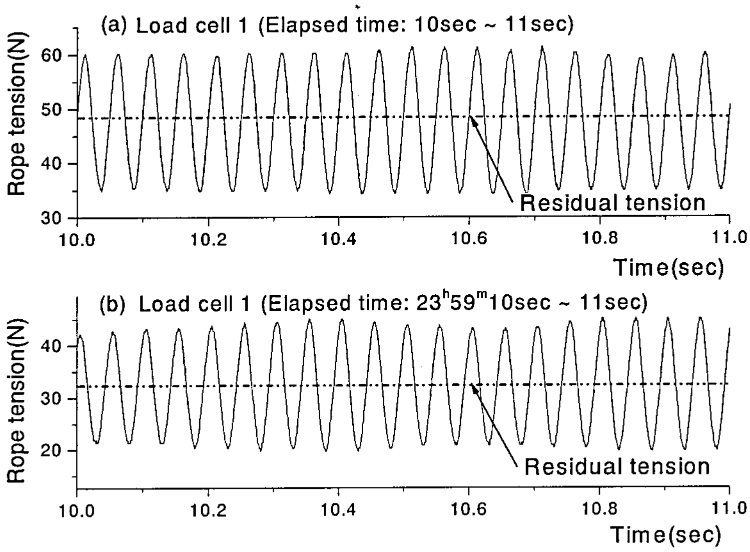


Figure 4- 9 Time history of rope tension at resonant frequency

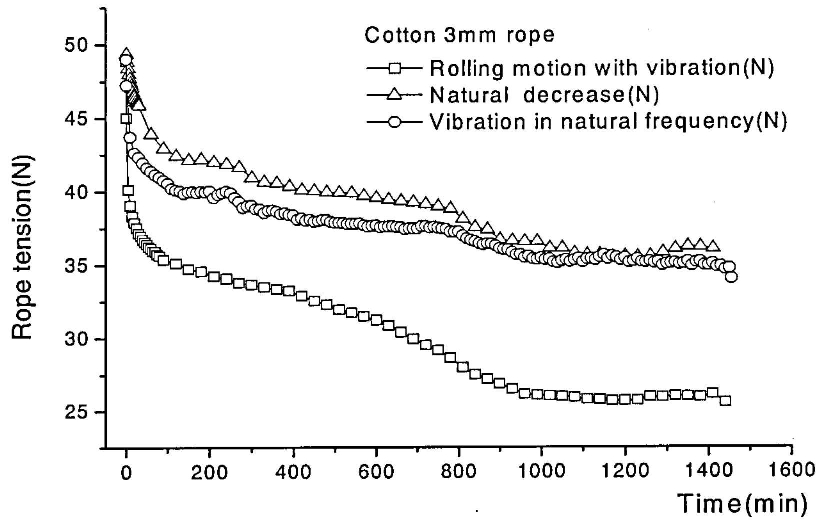


Figure 4- 10 Comparison of rope tension responses

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. 4-5. 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.

4.2.3 Synchronized oscillation test

The relationship between the fluctuation rope tension and residual one by rolling motion was compared in the previous section.

4.2.3.1 Condition of experiment

In this section, the experiment was carried out for the rope tension behavior according to synchronized motion with heaves one.

The experiment conditions are summarized in Table 4.4.

Table 4. 4 Experiment condition with synchronized motion

Motion	Frequency(Hz)	Roll Angle Heave Amplitude		Initial Phase Difference
Roll	0.25	Angle	± 5 or 10°	0, $\pi/2$, π, $3\pi/2$
Heave	0.1, 0.2, 0.3, 0.4, 0.5	Amplitude	20cm	
Roll	0.25	Angle	± 5 or 10°	
Heave	0.1, 0.2, 0.3	Amplitude	10cm	

4.2.3.2 Result of experiment

Figure 4-11 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 motions 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.

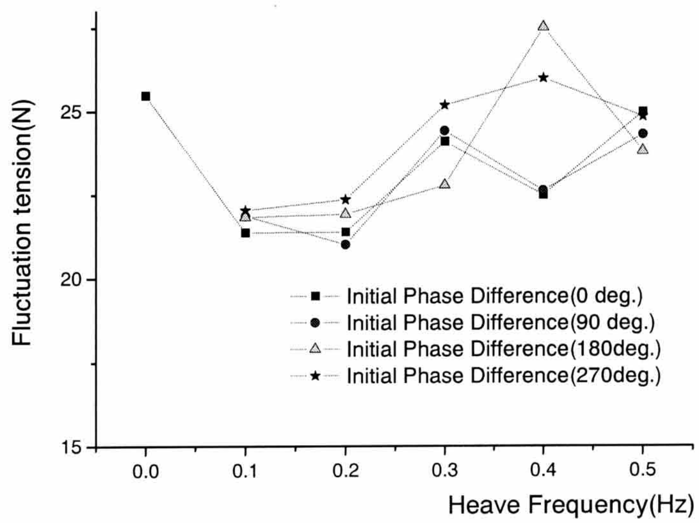


Figure 4- 11 Comparison of fluctuation tensions according to phase angle

4.3 Comparison of residual tension

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 could be confirmed that the residual tension of securing rope decreased by cyclic loading under transportation. But, there are many cases that cannot use such an experiment. Therefore, to verify the effectiveness of predicting of residual tension carried out the cyclic load test by the cyclic loading tester.

4.3.1 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. However, the rope tension was decreased by the repeated motion, and its range became 15 ~ 35N after about 24 hours, as shown in Fig. 4-4.

4.3.1.1 Condition of experiment

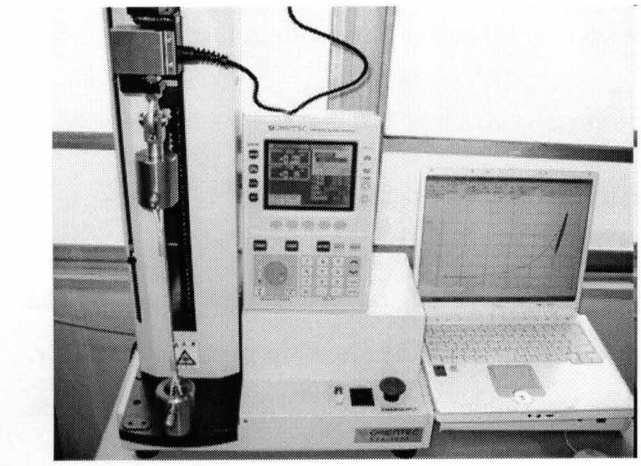
The experimental condition is as following and in Table 4.5.

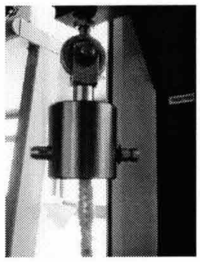
- A number of cyclic load : 1000times
- Sampling rate of data recording : 20ms
- Initial tension of rope : 49N
- Temperature and Relative Humidity : 25℃, 60%
- Frequency of cyclic load test : 0.26Hz
- Software of data processing : A-AND-D MAST02 and 04V2 for cycle test
- Load tester : A-AND-D STA1225

Table 4. 5 The general specification of rope

Type		a	b	c	d	e	Loa(mm)
Rope – Cotton, ϕ 3mm	I	30	30	140	40	30	270
	II	30	30	145	35	30	270

Figure 4-12 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. 4-2. Therefore, the cyclic loading was set between two displacement amplitudes (Fig.4-13), 25.3 and 26.8mm, at the cyclic loading tester.



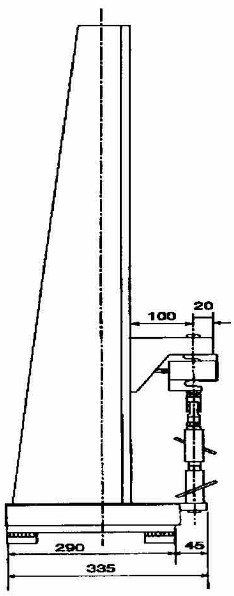


(Top)

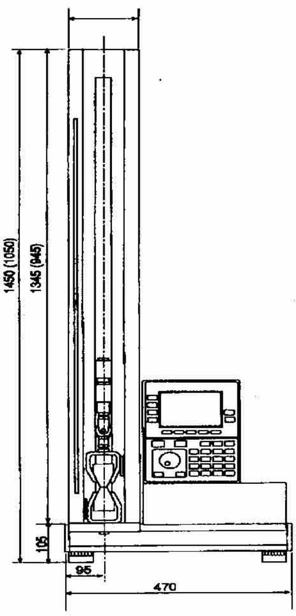
(Bottom)

(In front view)

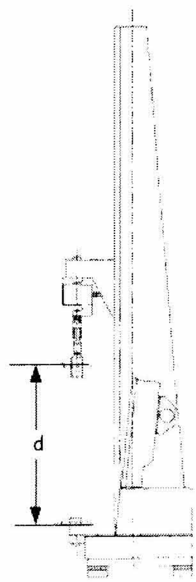
Figure 4- 12 Configuration of cyclic loading tester



(Side view)



(In front view)



(d: Displacement amplitude)

Figure 4- 13 Specification of cyclic loading tester

Figure 4-14 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.

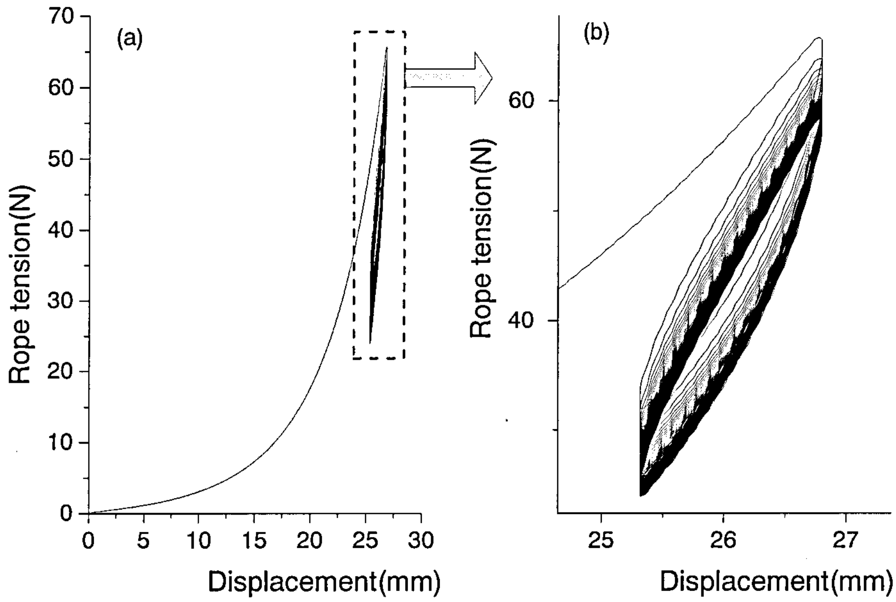


Figure 4- 14 Cyclic rope tension response of cotton rope type- II

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

4.3.2.1 Calculation of residual tension by cyclic load test

Figure 4-15 shows the schematic diagram of calculation method for the residual rope tension under the cyclic loading test. The residual rope tension, $RT_{cycle}(n)$, at cyclic loading times n was defined as the following Eq. (4-1), as shown in Fig. 4-15.

In case of the cotton rope type- II, the mean displacement amplitude of cyclic loading time is 26.05mm

$$RT_{cycle}(n) = \left(\frac{F(n) + f(n)}{2}\right) \tag{4-1}$$

Where,

$F(n)$ is maximum rope tension at the mean displacement amplitude

$f(n)$ is minimum rope tension at the mean displacement amplitude

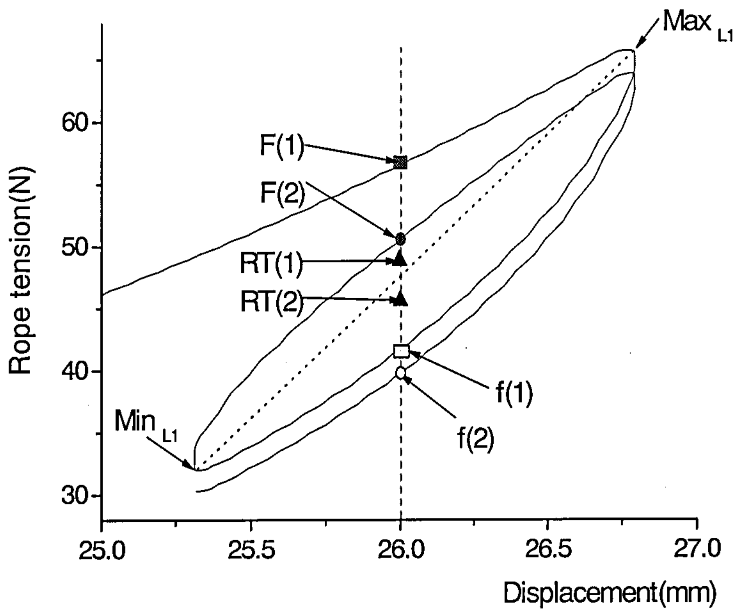


Figure 4- 15 Schematic diagram of residual cyclic rope tension

4.3.2.2 Comparison of residual tension of two tests

Figure 4-16 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. 4-10 was converted into that according to cyclic count.

Their residual rope tensions are also summarized in Table 4.3 with the percentage of accuracy CR(%) as defined in Eq. (4-2).

$$CR(\%) = \left(\frac{\text{Cycle loading test} - \text{Oscillation test}}{\text{Oscillation test}}\right) \times 100 \qquad (4\text{-}2)$$

As shown in Fig. 4-16 and Table 4.6, it could be found that these two residual rope tensions were in good agreement with each other.

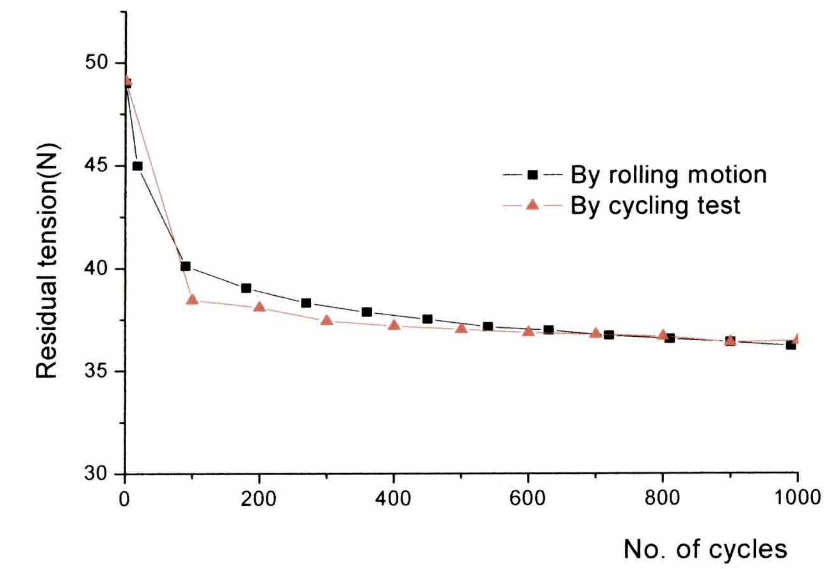


Figure 4- 16 Comparison of residual rope tension between oscillation test and cyclic loading test

Table 4. 6 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

4.4 Conclusion

In this chapter, 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 motions and synchronizes with heave motion.

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

References

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Chapter 5 Optimum Initial Tension of Securing Rope

5.1 Prologue

In the previous Chapter 3 and 4, according to the cyclic loading test by the expected fluctuation tension (1), the residual tension of securing rope could be predicted (2).

In the long distance voyage, the cargoes receive the external forces repeatedly. So, the definite securing and a lot of attention are demanded for prevent of cargo accidents such as the movement or collapse of cargo by ship motions in sea-waves

In actual, it is impossible to monitor continuously. So, it is necessary that the set of the optimum tension of the securing rope based on the quantitative evaluation

In this Chapter, the concept of minimum safety tension and safety degree is introduced to quantitatively evaluation of residual rope tension, and the safety degree is evaluated by the residual tension curve.

Next, in order to the decision of optimum initial tension of securing rope, the residual tension is measured in case of the initial tension is some difference, and compared relationship between the number of cyclic loading and the non-dimensional residual tension.

5.2 Safety of securing rope

Generally, the cargoes are unitized by the pallet and/or the container for the efficient and safe transportation.

To prevent damages of cargoes by the shock and vibration, the optimum transport packaging technology are applied to the packaged products, for example, the selection of the cushioning materials, the development of the packaging design and the durability improvement of products.

In addition, although cargoes are secured based on the cargo securing manual, the securing devices should be always monitored by the operators. But, the securing rope tensions are checked according to the experience, and then there is a personal difference on a judgment for the cargo securing works. For the safety transportation, therefore, it is necessary that the set of the optimum tension of the securing rope and quantitatively evaluation of the securing works.

5.2.1 Residual tension by cyclic loading

Through the prediction of the fluctuation tension, the residual tension curve by the cyclic loading was drawn. The range of fluctuation tension of securing rope by roll motion was measured about 30N in the previous work·

The next experiments were carried out to confirm on the residual tension curve by a variety of initial tensions. Then, the cyclic loading test is controlled in the range of fluctuation tension by initial tension ± 15N. For example, in case of initial tension is 98N, the range of cyclic loading is set up an 83 ~ 113N.

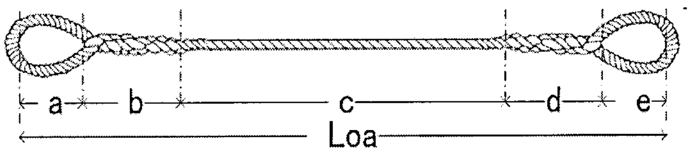
The residual tension by cyclic loading test is calculated by the arithmetical mean of the range of cyclic loading.

Table 5.1 shows the experiment conditions, and the composition of the cyclic loading tester is described in the Chapter 4(Fig. 4-12, 4-13).

- Type and diameter of rope : Cotton, ϕ 3mm
- Counts of cyclic loading : 500 times
- Sampling rate of data recording : 20ms
- Speed of testing : 5 mm/min

Table 5. 1 Condition of cyclic loading test

Initial tension	a	b	c	d	e	Loa	Temp. (℃) R.H. (%)	Frequency of cyclic loading (Hz)
49N	30	25	170	30	25	280	15℃, 58%	0.03
60N	30	30	170	30	30	290	17℃, 52%	0.03
70N	30	20	175	30	27	282	18.5℃, 53%	0.035
80N	30	35	170	37	38	310	18℃, 50%	0.035
90N	30	30	175	21	26	282	16℃, 59%	0.042
98N	35	25	185	35	30	310	17℃, 53%	0.038



unit:(mm)

Figure 5-1 shows a result of the residual tension by cyclic loading. The horizontal axis is number of cycles. Vertical axis is residual tension and the residual tension of an each initial tension is decreased little by little.

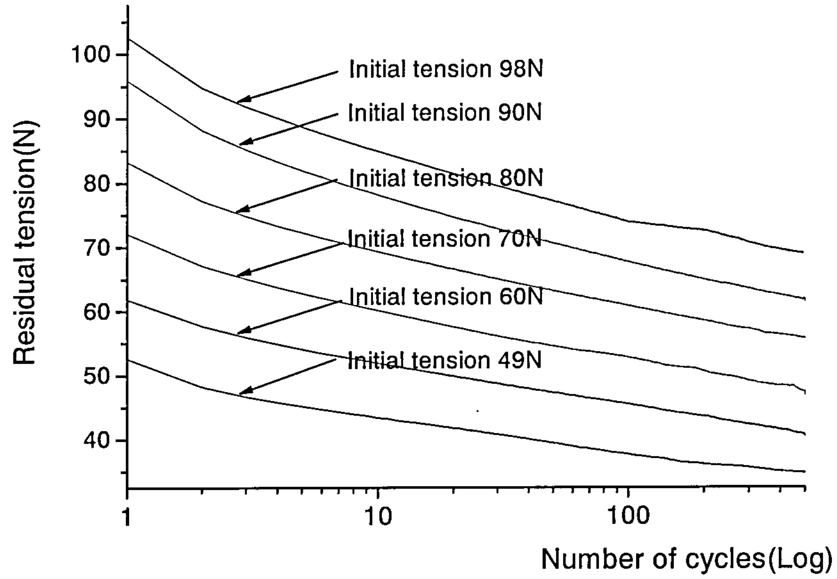


Figure 5- 1 Residual tension decreasing by cyclic loading

5.2.2 Safety factor

According to JIS Z 8115, "the safety" is defined that the danger of the harm to the person or the damage of materials to be in the state suppressed to the allowable level.

If the residual tension or fluctuation tension of securing rope in regard to the external force is within the allowable level, the securing cargo is safe. On the contrary, it can be said that additional securing devices or appropriate tension of securing rope are necessary to prevent of cargo accidents.

5.2.2.1 Minimum tension of securing rope

The external forces acting on the cargo unit in longitudinal, transverse and vertical directions were calculated using the formula in shown Chapter 2. Also, cargo securing operation shall be carried out and evaluated according to recognized principles, for example calculation program in accordance with Annex 13 to the CSS code 2003 edition from IMO or methods accepted by the administration, taking into account dynamic forces that may occur under transportation.

The friction contributes towards prevention of sliding. The following friction coefficients (μ) should be applied.

- Timber-timber (wet or dry) : 0.4
- Steel-timber or steel-rubber : 0.3
- Steel-steel (dry) : 0.1
- Steel-steel(wet) : 0

Figure 5-2 shows the forces acting on the inclined object. If the forces of acting on units are exceed to the MSL of securing devices or a change of securing rope tension by cyclic loading, a permanent stretch of rope or the lose of securing efficiency will be possible to cause the cargo accidents.

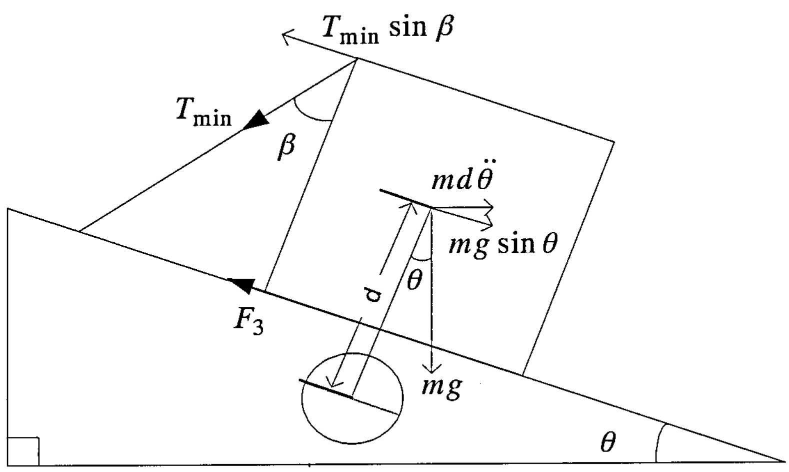


Figure 5- 2 Balance of forces on inclined object

Where,

F_3 : Frictional force

m : Mass of object

β : Angle of rope

d : Vertical distance between the center of motion and the center of weight

T_{min} : Minimum tension for safety securing

$\theta = \Theta \sin(\omega_\theta t + \varepsilon_\theta)$: Displacement of roll motion

$\ddot{\theta}$: Acceleration of roll motion

g : Gravitational acceleration

To the safety of securing, therefore, the minimum tension for safety securing ($T_{\min}$) is defined as following condition.

- On the friction coefficient(μ) is 「0」 ; non-frictional condition

The horizontal balance of forces on the non-frictional condition can be showed by equation (5-1).

$$T_{\min} = \frac{1}{\sin\beta}\left(md\ddot{\theta} + mg\sin\theta\right) \qquad (5\text{-}1)$$

The securing rope tension is fluctuated by the ship motions; especially the rolling is most serious in marine transportation. So, as shown in Table 5.2, we set the natural period and amplitude of rolling by classification regulation [3].

Table 5. 2 Ship motion

Mode	Amplitude	Natural period (sec)
Roll	$\theta = 30°$	$T_r = \frac{0.7B}{\sqrt{GM}}$

Where,

θ : Maximum single amplitude of roll, in degrees

B: Breadth of ship(m)

GM: Transverse metacentric height of ship(m)

5.2.2.2 Evaluation of safety

As shown in Figure 5-3, the safety of securing rope can be proposed by evaluating on the residual tension. The load acting on the securing rope is fluctuated and the residual tension is reduced by the external force. The solid line is the virtual line of the predicted residual tension; dot line is residual tension by calculation with the arithmetical mean of measured rope tension, and the minimum safety tension ($T_{\min}$) should be decided by the equation (5-1).

The safety degree (SD) of residual tension can be evaluated by minimum safety tension, as shown in equation (5-2). The securing object is not moved by oscillating motion when the SD is bigger than 1 (a), so the securing condition is safe within the elapsed time (b). If the value of fluctuation tension is same of residual tension like as (c), on the other hand, SD is evaluated as 「0」.

In this case, therefore, it is necessary to additional operation before the time elapsed to prevent cargo accident from potential hazards.

$$\text{Safety degree(SD)} = \frac{\text{RT} - \text{FT}}{\text{T}_{\text{min}}} \quad (5\text{-}2)$$

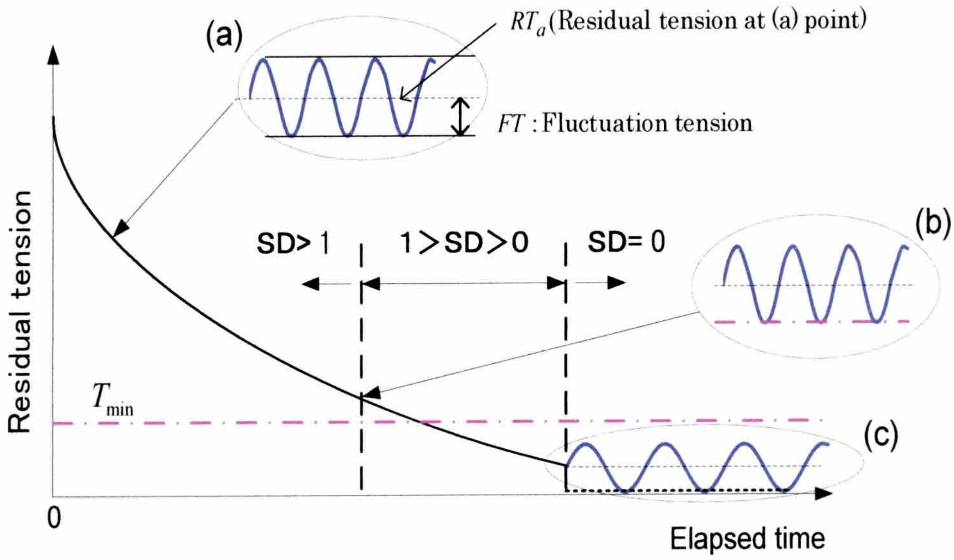


Figure 5- 3 Evaluation of safety degree by residual tension of rope

5.3 Decision of optimum initial tension

The most of research was the optimum loading of stowage, the lashing method of securing rope and strength of container by the external effects under transportation. Moreover, a lot of equipment is used to prevent from movement of cargo by ship motions.

In order to maintain the tension of rope, 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. Thus the decision of optimum initial tension is very important.

5.3.1 Non-dimensional residual tension

Figure 5-4 shows a comparison between the number of cyclic loading and the non-dimensional residual tension based on the different initial tension in Fig. 5-1.

As a result, the reducing rates of the non-dimensional residual tension are not so much difference even at the initial tension is not same.

Therefore, it is not necessary to confirm on the residual tension curve by a variety of initial tensions by the experiments.

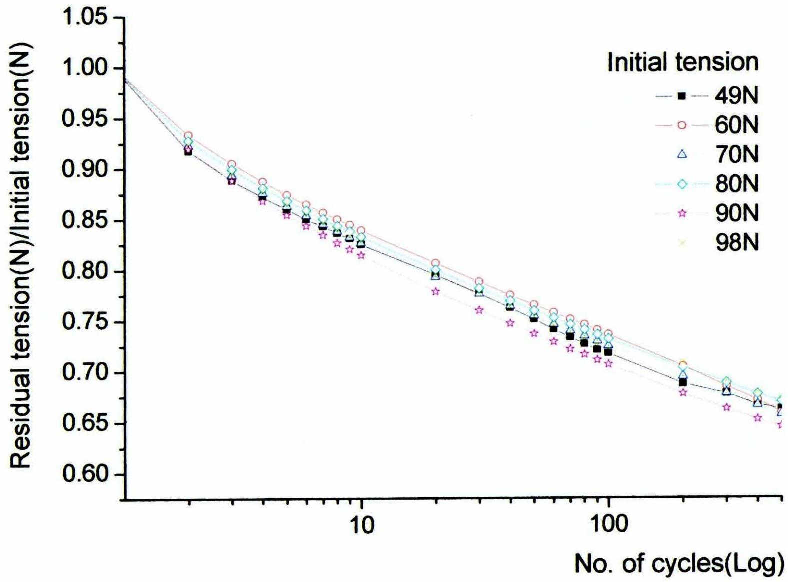


Figure 5- 4 Reducing of non-dimensional residual tension at the several initial tensions

5.3.2 Decision of safety initial tension

Figure 5-5 shows the concept of decision for the optimum safety initial tension of securing rope.

First of all, the minimum safety tension (T_{min}) should be decided by the equation (5-1) to prevent the movement and the collapse of cargo in worst oscillation. As shown in Figure 5-2, it is mean that the safety of securing cargo is not sufficient in that case of residual tension is lower than T_{min} and need more tighten up the rope tension or additional securing works.

The solid line of Fig. 5-5 is the virtual line of the predicted residual tension during arbitrary securing period.

As a method of settlement, the safety tension can be secured by raising an initial tension like as the broken line of Fig. 5-5.

At this time, a safety initial tension of securing rope can be set again by parallel moving the residual tension curve to touch the minimum safety tension as the result of Fig. 5-4. It will be possible to make a secure of safety of securing rope under the securing period through the resetting of the initial tension.

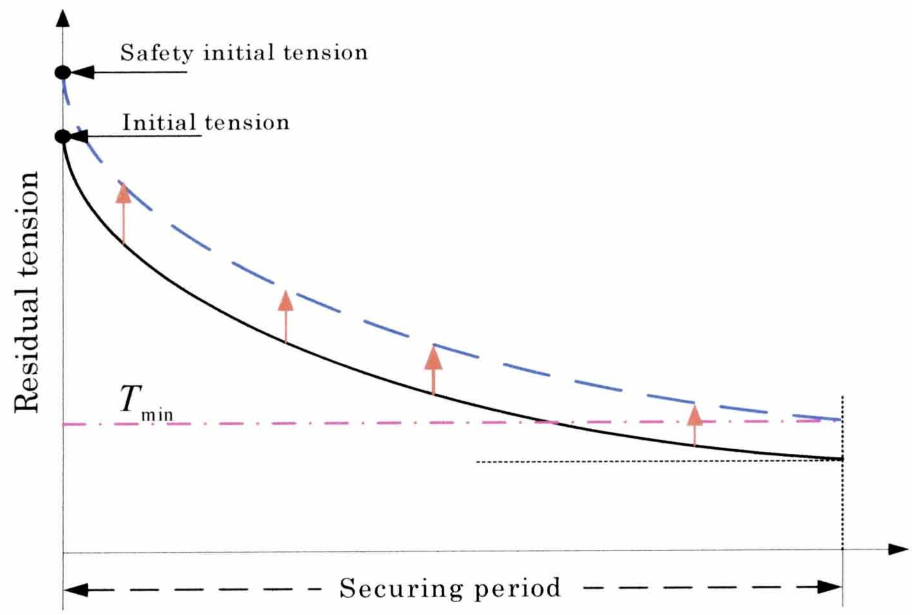


Figure 5- 5 Schematic decision for safety initial tension of securing rope

5.4 Conclusion

In this paper, we carried out the experiment and analysis for the decision of safety initial tension of securing rope.

The results can be summarized as follows.

(1) The safety concept is applied for the decision of safety rope tension by residual tension, and the tension of securing rope is evaluated quantitatively.

(2) The decrease rate of the residual tension is almost the same tendency at any initial tension.

(3) The reliability and safety of rope tension by evaluating of safety degree is improved, and then field workers can be applied based on the proper method, for example the selection of rope or tightening work of rope tension, etc.

References

(1) Kim, Y. D. and Saito, K. (2007), "The Prediction of Fluctuation Tension of Securing Rope by Oscillation", Journal of Packaging Science & Technology, JAPAN, Vol. 16, No. 6, pp. 413-423.

(2) Kim, Y. D. and Saito, K. (2008), "Prediction of Residual Tension of Securing Rope by Oscillation Test", Journal of Navigation and Port Research, International Edition, Vol. 32, No. 7, pp. 537-542.

(3) Lloyd's Register (2005), "Rules and Regulations for the Classification of Ships", Cargo Securing Arrangements, Part 3, Chapter 14.

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Chapter 6 Conclusion and Discussion

In the event of long-distance marine transportation, it is very difficult to safe transport and to keep the cargo condition better than other transport vehicles, because of a lot of external effects acted on the securing devices and packaged freight by ship motions repeatedly.

At the securing operation, therefore, the tension of securing rope should be evaluated by considering the safety and economical efficiency.

In this research, field observations and experiments were carried out in order to evaluation quantitatively the safety.

In **Chapter 2**, presents the concept of appropriate packaging and securing to prevent cargo accidents by the stress occurred under transportation. Furthermore, the method and the flow of securing works based on the Cargo Securing Manual were grasped through the observation of field and questionnaire survey.

Based on the presented, the obtained results are summarized below.

(1) For the safety transportation, it is need not only proper securing, appropriate packaging, but also the consideration or support of technical and management system, for example, operator training and safety education with cargo handling technique, the development and application of new technology, and replacement of equipment.

(2) 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. It leaves much room for considerations, in case of the selection of the securing devices, because of those were acted on cyclic loading by the hull motions, and a permanent stretch of the rope will be possible to causes the freight collapse and the movement accident.

(3) In accordance with Annex 13 to the CSS code 2003 edition, the external forces action on a cargo unit in longitudinal, transverse and vertical directions should be calculated. Actual stowage and securing plan must then be checked against the ship's computer loading/lashing program and/or CSM to ensure that permissible limits are not exceeded.

(4) As see the result of observation of field and questionnaire, the operators usually decide the cargo handling methods based on the manual and their practical experience. Especially, the rope tension is not measured by measuring instruments and most of field worker was depended on their experience.

(5) 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. For the safe transportation, therefore, setting of the optimum tension of securing rope is necessary to do certainly through the quantitative evaluation.

In Chapter 3, for prediction of fluctuation tension of the force to act on cargo securing rope by motion, carried out the experiment using the ship motion simulator. Consequently, the prediction of fluctuation tension was verified by experiment as the same condition.

From the analysis, the results are summarized as follows.

(1) We derived mathematical equations to calculate of the fluctuation tension acted on the securing cargo units by oscillation.

(2) As a result of experiment, we confirmed that extend of the changing a estimated frictional force by formula and tension of rope according to change a frequency of simulator and type of rope.

(3) The approximation straight line displayed to through compare of the relations between the inclined angle and frictional 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.

(4) We predicted the fluctuation tension in case of the arbitrary frequency of rolling and initial tension using data obtained through the experiment.

In Chapter 4, for prediction of residual tension of the rope was carried out two tests, and were compared with each other; because 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 and improper securing.

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 fluctuating range of rope tension was little change makes a comparison between only rolling motion and synchronizes with heave motion.

(3) The fluctuation tension of securing rope exists mixed with the component of low frequency and high frequency under 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 **Chapter 5**, for the decision of safety initial tension of securing rope, the safety concept was introduced, and carried out the experiment and analysis.

The results can be summarized as follows.

(1) The safety concept is applied for the decision of safety rope tension by residual tension curve and the tension of securing rope is evaluated quantitatively.

(2) The decrease rate of the residual tension is almost the same tendency at any initial tension.

(3) The reliability and safety of rope tension by evaluating of safety degree is improved and then field workers can be applied based on the proper method, for example the selection of rope or tightening work of rope tension, etc.

If experiments on various conditions (for example, other material, transportation environment and so on) and the database are made, it will be possible to prediction of fluctuation tension and residual tension of securing devices by the motions.

Furthermore, it is necessary that when the settings of the minimum safety tension, the check of the transportation environment or the level of external forces, and the proposed method should be improved by checking on the residual tension in actual condition.

Additionally, it is more need research to set of optimum rope tension and to safety evaluation of the rope tension on the various conditions and structure of material, and the simply checking and measuring method of rope tension in the field.

Acknowledgement

I would like to express my deep gratitude to Professor Katsuhiko SAITO for his significant assistance and guidance in my research, but also for contributing in large in my life in Japan. Professor Saito provided me a significant amount of resources at the start of my research; his advice during my graduate studies was invaluable.

I would also like to thank Professor Hiroyuki SADAKANE for the opportunity he gave me to studying with exchange student in Kobe University before about 7 years. He has provided me with more resources and experience than I feel have deserved about living in Japan. Especially, he was checked my Japanese diary every day for a Japanese ability improvement. Thanks for all the advice and encouragement, academic and personal.

I thank Professor Ryuichi KIMURA and Akihisa ABE from the bottom of my heart for proofreading and editing the manuscript.

Additionally, I appreciate Professor Kazusei YAMAMOTO of Marine Technical College and Masanobu EGUCHI, Hitoshi HEI of Sankyu INC., who gave me constructive suggestions and assistant toward the experiment.

Also, I have to express to Professors Masayoshi KUBO, Hiroshi ISHIDA, Shigeru NISHIO, Captain Yoshiji YANO and Associate Professor Shino TAKANASHI, Koji KURAOKA of Kobe University. I also gratefully thank the administrative officials and staff of Faculty of Maritime Science of Kobe University.

Furthermore, I would like to express appreciate to current and past members of our laboratory, and my Kobe University friends for academically and socially stimulating my life. They are Jiang LI of Rengo, TAMURA of Olympus Company, Akinori IKEMOTO of Naval Architecture Engineering Lab., etc. Also thanks to the many others that I have not mentioned who contributed in some way to my research and life of Japan.

I am especially grateful to Professors Soon-Kap KIM, Choong-Ro LEE, Gil-Young KONG, Chol-Seong KIM, Yun-Sok LEE, Sang-Min LEE and Dr. Ik-Soon CHO, Chang-Hyun JUNG in the OASYS Family of KMU. I wish to express my special thanks to Professor Ihl HUGH, Si-Hwa KIM, Kwon-Hae CHO, Seong-Hyeok Moon, Eun Bang LEE, Jin Soo PARK, Se Won KIM of Korea Maritime Univesity.

I would like to thank Nakahara Family; especially Woo & Kiyomi shows a shining sample of the family.

I thank to MUGUNGHWA Members. I had a great happy time to study Korean with MUGUNGHWA Members. Also, I thank Korean students of Kobe University with good memories. There are many more people I would like to thank but could not mention all of them again, including big senior Soon Won CHO, S.W BECK, Ho Sung Lee of KR (Korea Register of Shipping) Kobe office, Jin Sop Choi of Heung-A shipping Co. LTD, Hoe-Sik KIM of KMU KANSAI, Dae Sung KIM of CASCO, Kyung Woo KIM of Grow-Will Co., and all my friends.

I thank my parents and wife's parents, who supported and encouraged me in continuing my studies in the Japan. Thank you for always setting the example.

Last, but most importantly, I would like to thank my wife, Hwa Jung CHO, who were always supportive and were behind this effort totally, and my daughter, Shi Ha KIM. I dedicate this work to them.

List of Publications

Journal articles

(1) Kim, Y. D. and Saito, K. (2007), "The Prediction of Fluctuation Tension of Securing Rope by Oscillation", Journal of Packaging Science & Technology, JAPAN, Vol. 16, No. 6, pp. 413-423.

(2) Kim, Y. D. and Saito, K. (2008), "Prediction of Residual Tension of Securing Rope by Oscillation Test", Journal of Navigation and Port Research, International Edition, Korean Institute of Navigation and Port Research, Vol.32, No.7, pp537-542.

(3) Kim, Y. D. and Saito, K. (2008), "Optimum Initial Tension of Securing Rope", Journal of Packaging Science & Technology, JAPAN, Vol.17, No.5, pp357-365.

Conference papers

(4) Kim, Y. D. and Saito, K. (2009), "Study on Optimum Tension of Securing Rope", 24^{th} IAPRI Symposium, USA, CD-ROM, May

List of Pictures and Tables

Appendix A Questionnaire

固縛索に関するアンケート

神戸大学大学院　海事科学研究科
輸送包装研究室

貨物の移動や荷崩れを防止するために固縛をしますが、輸送中に発生する外力によって固縛索に繰り返し荷重が作用します。そのため、固縛張力は少しずつ減少し、索の残存張力が小さくなり過ぎ、目的地まで安全に運ぶことが不可能になることもあります。

本アンケートは貨物固縛及び固縛ロープの張力に対する現場調査を目的として実施するものです。 なお、本アンケートは合理的な固縛索の張力設定のための研究に利用する以外には使用しないことを付け加えておきます。

該当項目を○で囲んでください。

1. 回答者の属性について

1) あなたの現場経験年数を下から選んで下さい

① 3年未満　② 3年～5年　③ 5年～10年　④ 10年以上

2) 現在現場作業に従事していますか？

① している　② していない

3) 固縛している貨物が何らかの原因で荷ずれや荷崩れを起こした、又はそのようなことを見聞したことはありますか？

① ある　② ない

2. 貨物固縛指針書について

IMO(国際海事機関)の規定に準拠し、NK（日本海事協会）には海上輸送貨物の不十分な固縛による事故防止のため、貨物固縛指針書を作成し、それを船舶に搭載することを義務化しています。

1) 貨物固縛指針書について

① 内容を理解しているし、指針書に記載されている内容をもとに作業マニュアルを作成・利用している

② 内容は理解しているが、指針書に記載されている内容をもとに作業マニュアルは作成・利用していない

③ 内容を理解していない

2) 上記1)で①とお答えになった方に質問です。その理由は?

① 貨物事故防止に実際に役に立っているから　② 貨物固縛担当者や上司からの指示

③ 経験者にとっても参考になるから　④ 関連団体での申し合せ等があるから

⑤ その他 〔　　〕

3) 上記1)で②とお答えになった方に質問です。その理由は?

① 貨物事故防止に実際に役に立たなかったから　② 関連団体での申し合せ等がないから

③ 実際の作業に活用するのに繁雑だから　④ 経験に基ずく固縛作業で十分に安全だから

⑤ 会社等で独自に決められている作業マニュアルがすでにあるから

⑥ その他 〔　　〕

4) 上記1)で③とお答えになった方に質問です。その理由は?

① 指針書に関する教育を受けた事がない　② 指針書に関する教育を受けたが忘れた

③ 内容が難しい　④ 実際の作業に役に立つとは思えないから

⑤ その他 〔　　〕

3. 貨物固縛方法について

1) 固縛索の種類・数及び固縛方法を決める根拠は何ですか

① 固縛指針書に記載されている内容をもとにした作業マニュアル

② 会社等で独自に決められている作業マニュアル

③ 長年の経験にもとずいた判断

④ その他 〔　　〕

4. 固縛ロープの張力について

1) 固縛索の初期張力*①の設定方法について

① できるだけ高い張力　② 経験による適切な張力　③ 破断強度を参考にした適切な張力

④ その他 〔　　〕

2) 固縛作業後の初期張力を点検する方法について

① 自分の経験にもとずく感覚　② 装置類を用いて計測　③ 特に点検しない

④ その他 〔　　〕

3) 固縛索の残存張力*②に対する点検する方法について

① 自分の経験にもとずく感覚　② 装置類を用いて計測　③ 特に点検しない

④ その他 (　　　　　　　　　　　　　　　　　　)

*① 初期張力: 貨物の移動を防止するために固縛作業の時に加えられるロープの張力

*② 残存張力: 時間の経過とともに少しずつ減少していく張力

5. その他、固縛張力の設定に関して、改善すべき点などがあればご記入下さい。

お忙ししところ、ご協力ありがとうございました。　以上