IMPROVEMENTS IN WINCHES DESIGN GUIDE

AM 11

THESIS

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ABSTRACT

As the load requirements increase in the shipping industries, the design of drum winches with a larger thickness is required. This results in an increase in material used as well as machining and manpower costs. All these production costs will eventually hit a limit and the design codes cannot be met.

The safety factor used for industries today is based on design guides required by the inspection bureau. It is believed that this safety factor results in an over-design for the drum winches. Briefly, the safety factor calculation is based on the first layer concentration on the drum and expected multiplication of certain constants for layers thereafter. The fundamental assumption is that the tension exerted by the wire ropes on the drum is a constant for all the different turns and at different layers.

Based on the experimental data obtained, a suitable improvement to the design guideline will be proposed.

Besides the academic positives of this research, it has also practical and economical implications as the previous suspected over-designed winches actually result in much higher material, machining and manufacturing costs.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS

Symbol		Page
DNV	Det Norske Veritas	1
SAA	Standards Association of Australia	1
σ_h	Hoop Stress	5
S	Rope tension under spooling	5
p	Pitch of rope grooving	5
t_{av}	Average wall thickness of the drum barrel	5
C	Rope Layer Factor	5
f_o	Permissible hoop stress	6
R	Actual rope pull	6
t	Theoretical thickness	6
K	SAA Rope Layer Factor	6
F_1	Load	17
P_{JE}	Tension Correction Factor	18
σ_Y	Yield Stress	19
D_{drum}	Drum diameter	29
D_{rope}	Rope diameter	29
a	Rope Radius	29
v	Vertical Distance between the centre of 2 ropes in adjacent layers	29

CHAPTER 1: INTRODUCTION

1.1 OBJECTIVE

In this research, experimental data obtained would be analyzed so that suitable design guidelines would be obtained.

Firstly, experiments matching the real-life application will be conducted to investigate the phenomenon that occurs during loadings on drum winches. Thereafter, there will be meticulous analysis of the data collected.

Ultimately, it is hoped that the paper can serve as a reference for future drum winches design, providing a safe yet cost-effective design.

1.2 OVERVIEW

The preliminary phase of the research involves the literature survey on drum winch designs. The Det Norske Veritas (DNV) and the Standards Association of Australia (SAA) Crane Code were the two design guides being studied. Relevant resources for different wire ropes and their usages were also studied.

The next phase of the research required the design and fabrication of the drum winch. The considerations during this phase were the type of material and loads that the drum would have to sustain. The most difficult but also important aspect was to design a practical set-up that matches the industrial application, and at the same time working within the constraints imposed by the available space and equipment.

Further developments on this topic will include a site testing at Plimsoll Cooperation Pte Ltd. This will allow the gathering of data of real winch operations dealing with loads up to 400 Tonnes.

Figure 1a and 1b: Work at Plimsoll Corp Pte Ltd

1.3 SCOPE

The focal point of this project is to study the tension and elongation of the ropes that are on the drum. This in turn allows for some correction to the relevant design guides. Ultimately it is hoped that a suitable design guide is available without any over-design.

The report comprises of the following main parts: *Chapter 1* gives a simple and clear introduction and overview of the problem that is being analyzed. *Chapter 2* summarizes the literature review of previous works done on similar situations. *Chapter 3* deals with the materials and lab equipment used for the experiment. There will also be discussions on the measures taken to make certain that the readings on the equipment are precise. The drawing and pictures of the final set-up are also documented in this section. *Chapter 4* describes the steps taken during the execution of the experiments to ensure accurate data collection. Preparation of the experimental set-up, the exact steps in the experimental procedures as well as the safety precautions observed will all be covered in this section. *Chapter 5* details the results and observations gained from the experiments. Analysis and discussions will be included in this chapter also. *Chapter 6* will be the conclusion of the report and *Chapter 7* will mention any further improvements.

Chapter 2: Literature Survey

2.1 Overview

The groundwork phase of the research involves the literature search for the winch design. Wire rope guides as well as other information regarding ship winches were being scoured.

The available literatures gathered are from the Det Norske Veritas (DNV) as well as the Standards Association of Australia (SAA) Crane Code. The two codes state the minimum thickness of the winch drum that is required for the different number of layers of wire on the drum. However, these two codes only display the recommended requirements without any detailed analysis given.

2.2 Definition

The dictionary definition of a winch refers to any of various machines or instruments for hauling or pulling; *especially*: a powerful machine with one or more drums on which to coil a rope, cable, or chain for hauling or hoisting.

A more technical way of looking at a winch drum especially marine winch drum is to treat it as an entire system of machine that contains the following parts: the drum carrying the load, the power unit that drives the cranking process, the brake system that is activated to stop the cranking process and finally the rope that is used to hoist the load.

2.3 THE DNV DESIGN GUIDE

The fundamental assumption of this guide assumes that the rope is spooled under maximum ***uniform*** rope tension. It is assumed that all points of a wire rope under tension will experience the same tension. The design guides specifies that the hoop stress σ_h is not to exceed 85% of the material yield stress. The formula for the hoop stress calculation σ_h is:

$$\sigma_h = C \frac{S}{p \cdot t_{av}} \qquad \text{--------------------} \qquad (2.1)$$

Where

S = rope tension under spooling

p = pitch of rope grooving (distance between ropes, centre to centre within one layer)

t_{av} = average wall thickness of the drum barrel

C = rope layer factor,

With C = 1 for layer 1 and C = 1.75 for more than 1 layer.

The required thickness t_{av} of the drum could be calculated with all the other information available.

$$t_{av} = C \frac{S}{p \cdot \sigma_h} \qquad \text{--------------------} \qquad (2.2)$$

2.4 THE SAA CRANE CODE

The theoretical thickness t of the drum is obtained using the following formula:

$$t = K \frac{R}{p \cdot f_o} \qquad \text{--------------------} \qquad (2.3)$$

Where

R = actual rope pull

p = rope pitch

f_o = permissible hoop stress and

K = rope layer factor,

With

K = 1 for 1 layer of rope

= 1.3 for 2 layers of rope

= 1.5 for 3 layers of rope

= 1.6 for more than 3 layers of rope

The permissible hoop stress f_o is not to exceed 60% of the material yield stress.

2.5 COMMENTS

It is interesting to note that the formulas for the thickness of the drum are very similar for both the guides with the only key difference being the rope layer factor.

The above 2 design guides will be critically analyzed in *Chapter 5* of the report. The expected results obtained using these formulas will be evaluated to assess its feasibility.

Thereafter, the tension obtained experimentally will be used to show that simplifying assumption of a constant tension force experienced in the ropes is not justified and can thus cause an over design for the thickness of the drum as a result.

CHAPTER 3: EXPERIMENTAL SET-UP

3.1 MATERIALS

The first set-up of the experiment requires the construction of a winch drum that will be able to take loading of up to 200 Newton on the wire rope. The drum is made of mild steel with Young's modulus of 200GPa and thickness of 3 mm. The wire rope used for this part of the project is steel wire rope of 5 mm diameter. A support structure was built to house the mild steel winch drum to allow the coiling of the wire ropes to be done in an efficient manner. The support structure is made up of angle iron bars to provide stability for the entire set-up.

The second phase of the project requires a winch drum of smaller diameter. Acrylic was chosen as the material because it is relatively easy to cut to produce the desired design. The Young's modulus for acrylic is 1.6 GPa. The support structure was a mobile frame that was available in the laboratory. The rope used for this set of experiment is fishing lines of 1.2 mm diameter.

3.2 EQUIPMENT USED

The main measurement device used for the first experiment on the mild steel winch drum is the load cell, with a capacity of up to 200 Newton.

Besides the above mentioned constraint, there was also the need to place the load cell in a position to ensure that the tension that was transmitted would be at the centre of the load cell.

Two mini pulleys were used to centralize the load. The pulleys also act as a guide for the wire ropes to rest on the drum body. The load cell is fixed on an aluminum plate that was fastened to the side of the drum body. The load cell must be attached to the drum body this way so that the drum can be cranked to coil the wire ropes. A strain meter is used to display the readings of the load cell.

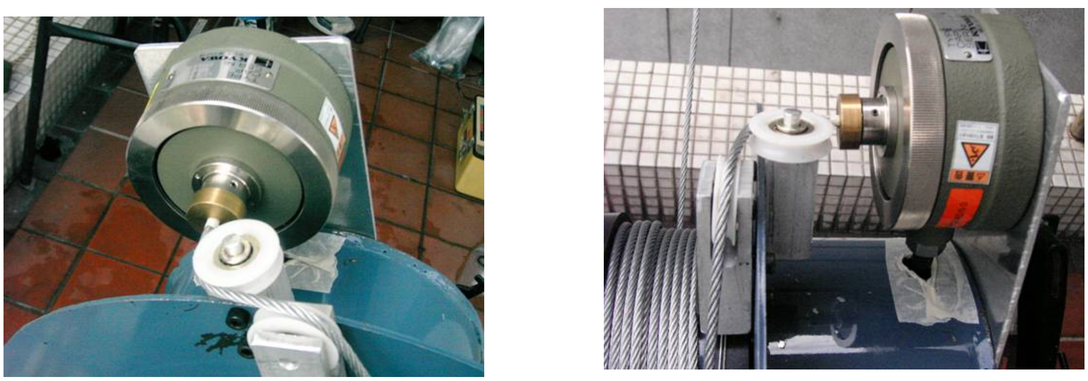


Figure 3.1a and 3.1b: Mounting of Load Cell

Figure 3.2: Strain Meter Readings

For the acrylic winch drum experiment, the point of interest was the elongation of the fishing line that is being coiled. Physical measurements on elongation were taken.

CHAPTER 4: EXPERIMENTATION

4.1 OVERVIEW

There were two different experimental set-ups for this project. One involves the use of the mild steel miniature drum winch of outer diameter 200 mm and length 300 mm. The other experiment is of a smaller scale and involves 2 acrylic spools of radius 60 mm, and of length 50 mm and 100 mm respectively.

The mild steel drum was used in conjunction with 5 mm diameter nylon ropes and wire ropes. The loads that were used during this experiment ranges from 44.5 Newton up to 107.9 Newton.

The experiment conducted on the acrylic drum on the other hand utilized nylon fishing lines. The diameter of the fishing ropes was 1.2 mm. Loads of 19.6 Newton, 29.4 Newton and 39.2 Newton were used during the experiment.

As the industrial usage involves very slow rotation, a quasi-static condition was modeled upon.

4.2 MILD STEEL DRUM WINCH

Because of the design of the mild steel drum winch, a great height is required for each layer of coiling.

Figure 4.1: Mild Steel Drum Final Set-up

Figure 4.2: Height required for experiment

Two different loading conditions were required. These are the procedures for the first condition:

1) A mass was placed on the hook and lowered until the rope was taut, applying a 44.5 Newton load. There were no turns on the winch drum body at this moment.
2) Thereafter the cranking of the winch drum was done. After each turn, the locking mechanism was put into place.
3) Reading will be taken from the strain meter which is connected to the load cell which was fixed on the drum flange.
4) After 12 turns have been conducted and the readings taken, the experiment and readings continue for the second layer.

5) After the second layer readings have been taken, the whole procedure occurs in the reverse, as the ropes are being uncoiled.
6) The uncoiling process is similar to the coiling one and readings on the strain meter were taken.
7) Steps 1 to 6 were repeated for the 44.5 Newton, 53.4 Newton and finally the 107.9 Newton load.

For procedure step 4, it must be noted that the number of turnings stopped at 12 on the next layer and not the full 60 coils. This was due to the constraint imposed by the height available for our experiment site. To do a full 60 coils will be an impractical as well as unsafe option.

The procedure for the second part of the experiment was to replicate the pull test:

1) The wire rope on the drum was turned to the 6^{th} turn. 26.7 Newton load was then applied. The locking mechanism was then put into place.
2) With the 26.7 Newton load providing a pre-tension, an additional 17.8 Newton of load was added to give a total of 44.5 Newton of load. Readings were taken from the strain meter.
3) Step 1 and 2 was repeated but with a pre-tension of 44.5 Newton, followed by a final load of 26.7 Newton. Similarly, readings were taken from the strain meter.

4.3 ACRYLIC DRUM WINCH

The design of the acrylic drum winch was much smaller in dimensions compared to the mild steel winch drum in the earlier part of the project. . The drum is made of transparent acrylic with an outer dimension 60 mm. The thickness of the drum is 4 mm. The full length of the drum from flange to flange is 100 mm as well as another one of 50 mm.

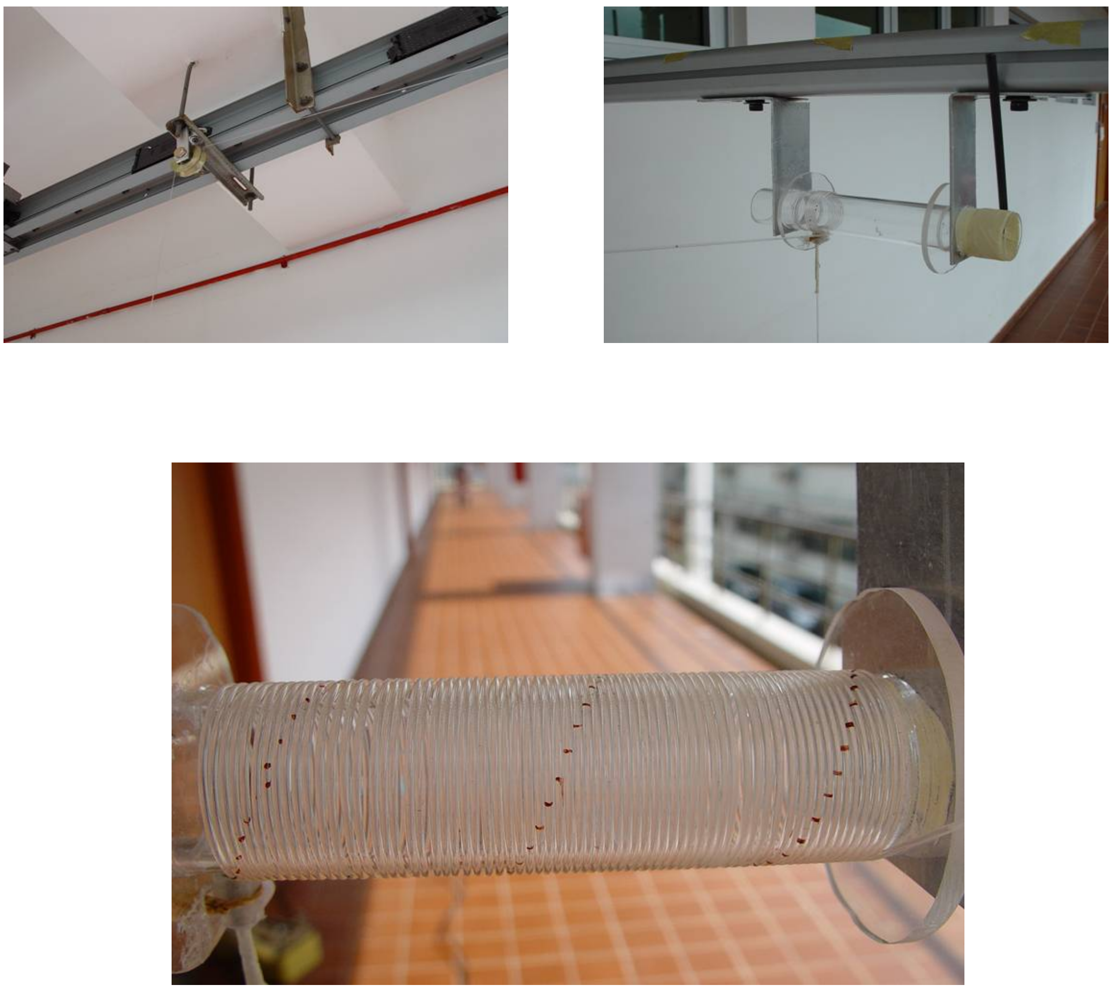


Figure 4.3a, 4.3b and 4.3c: Acrylic Drum Final Set-up

The rope used for this experiment is elastic nylon rope that has a diameter 1.2 mm, of total length 15 m.

The experimental procedures were similar to the ones carried out for the mild steel drum winch. The only advantage for this acrylic set-up is the availability of space for the full turns for each layer of the rope on the drum winch body.

The procedure for the pull test simulation was similar to that done on the mild steel drum winch. The procedures were similar except that readings of the strain meter for the load cell was replaced by the using the vernier calipers to measure the elongation values on the fishing line.

The procedure for the second part of the experiment to replicate the brake test:

1) There were no turns on the acrylic winch drum initially as the whole set-up was fully uncoiled. A 29.4 Newton loaded was applied.
2) The locking mechanism was then put into place. The elongation reading was taken of that part of the fishing line that had been already coiled on the drum.
3) Step 2 was repeated until there were 7 turns of the fishing line on the acrylic winch drum.
4) Coiling was done for the next round of turn on the acrylic winch drum.
5) After the reading had been taken for this turn, an additional 19.6 Newton load was applied until the total load was 49.1 Newton. The elongation measurements were taken again for the part of the fishing line that had been already coiled on the drum.

6) The load was then reduced back to 29.43 Newton by removing the 19.62 Newton load.

7) Steps 4 to 6 were repeated until the whole of the 1st layer had been filled.

8) Coiling was then done on the 2nd layer with the fishing line of the 2nd layer now resting on that of the 1st layer.

9) Steps 4 to 6 were now repeated until the whole of the second layer had been filled.

CHAPTER 5: OBSERVATIONS AND ANALYSIS

5.1 OVERVIEW

Empirical results obtained during the 2 experiments will be analyzed to show the reduction in the tension as the ***number of turns*** increases during the coiling processes. The number of turns on a drum actually refers to the number of rounds the rope has been wound on the drum body and Figure 5.1 shows a schematic drawing for the number of turns.

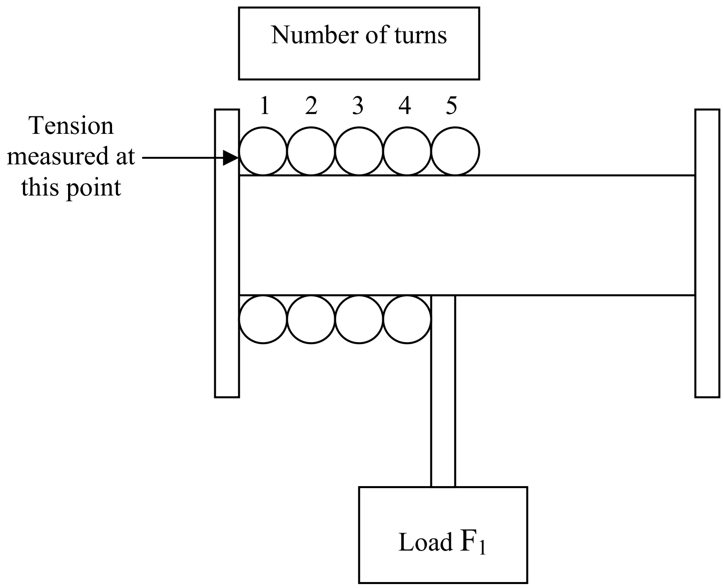


Figure 5.1: Illustration for the number of turns

The reduction in tension as the ***number of layers*** increase, during the coiling process will also be examined based on the constant applied torque. Figure 5.2 shows a schematic drawing for the number of layers.

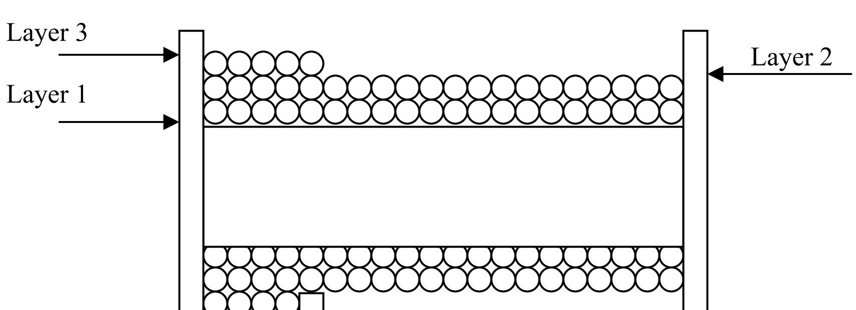


Figure 5.2: Illustration for the number of layers

Finally a ***tension correction factor,*** $\mathbf{P_{JE}}$ will be proposed to alter the existing guides with regards to the load applied to the winch. This correction factor helps to eliminate the simplifying assumption of a constant tension during the marine winch operations. This in turn affects the calculations of the thickness of the winch drums to be fabricated also.

5.2 COMPARING THE DNV AND SAA GUIDES

The followings are the formulas proposed by the two guides.

The thickness calculation for the Det Norske Veritas guide is:

$$t_{av} = C \frac{S}{p \cdot \sigma_h} \qquad \text{--------------------} \qquad (5.1)$$

The thickness calculation for the Standards Association of Australia guide is:

$$t = K \frac{R}{p \cdot f_o}$$ -------------------- (5.2)

As had been mentioned in Chapter 2 of the report, the 2 guides are very similar to each other except that the alphabets used are different for the same variable. The only significant differences between the 2 formulas however, lie in the correction factor *C* for the DNV and *K* for the SAA code, as well as the permissible hoop stress. For the DNV it is 0.85 σ_Y and for the SAA it is 0.60 σ_Y .

Table 5.1: Comparison of the drum thickness values for the two codes

	DNV		**SAA**	
	σ_h = 297.5 MPA		f_0 = 210 MPA	
	Layer factor *C*		Layer factor *K*	
Layer 1	1	t_{av} = 49.5 mm	1	t = 70.1 mm
Layer 2	1.75	t_{av} = 86.6 mm	1.3	t = 91.1 mm
Layer 3	1.75	t_{av} = 86.6 mm	1.5	t = 105.1 mm
Layer 4 and after	1.75	t_{av} = 86.6 mm	1.6	t = 112.1 mm

Given:

σ_Y = 350 MPa

S = R= 150 Tonnes = 150 x 1000 x 9.81 = 1471.5 kN

p = 0.1 m

The required thickness of the winch drum calculated from the two codes is presented on Table 5.1.

It can be seen from Table 5.1 that the thickness required for a 150 Tonnes load and 4 layer operation based on the SAA guide will be 112.1 mm. The fabrication process and machining for a drum with this thickness is extremely difficult. This thickness value will be even more difficult to meet with a heavier load of 300 Tonnes.

For such heavy loads (300 Tonnes), the industries cannot meet the design criteria imposed by the 2 relevant codes, as the fabrication of such a winch drum is not feasible and thus the usual practice is to design based on the first layer guidelines.

Though the design could not meet the requirements of the codes, thus far no failure of winches has been reported.

Figure 5.3: The brake test

The following sections aim to explain the differences between the design code and empirical evidence by investigating the possible decrease in tension when the number of turns increases within each layer. The decrease in tension when the number of layers increases, as a result of a constant applied torque; will also be examined.

5.3 DECREASE IN TENSION WITH THE INCREASE OF TURNS

The trend for all the graphs done for this part of the experiment are very consistent, showing a rapid decrease in tension of the wire rope at the flange end, within the first 5 turns. Thereafter, the tension continues to drop but much more gradually as the number of turns continue. This decrease does not occur unceasingly. It reaches an asymptote when the tension drops to around 75 – 78 % of the original load.

To illustrate the above, a schematic diagram Figure 5.4 illustrates the situation when there are 10 turns on the drum and show the position where the tension is being measured.

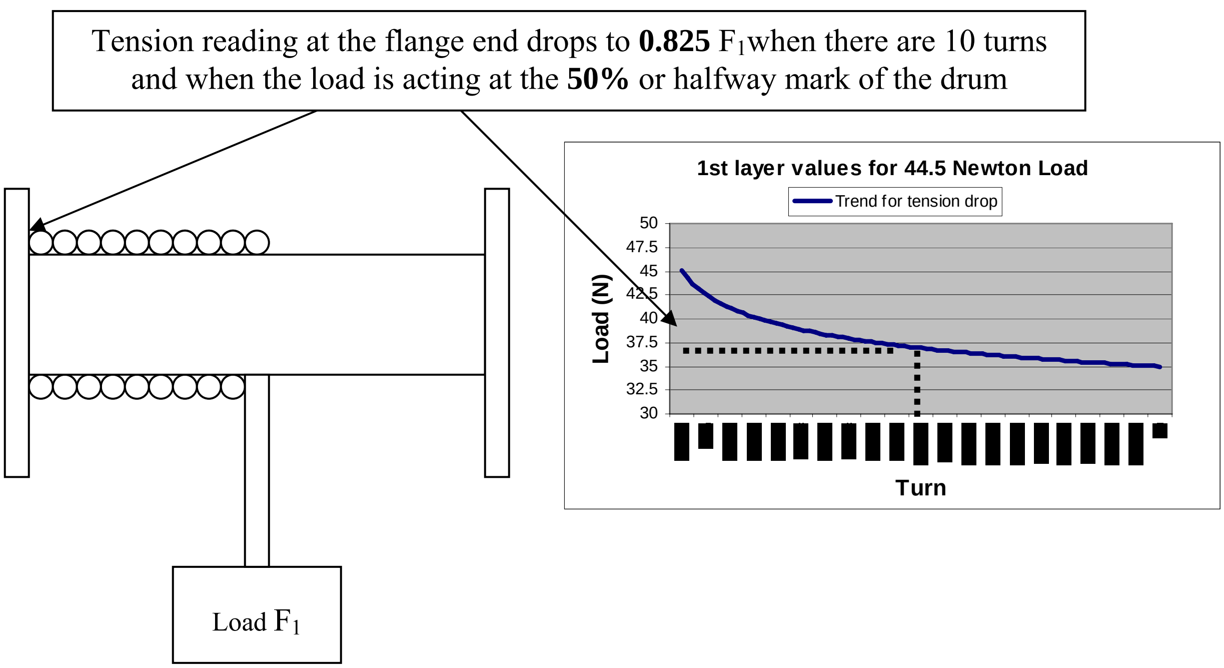


Figure 5.4: Measurement of the tension at initial point when the drum is 50% filled

The schematic of Figure 5.4 is based o the graph experiment conducted for the 44.5 Newton load and the trend for the tension decrease is shown in Figure 5.5 below.

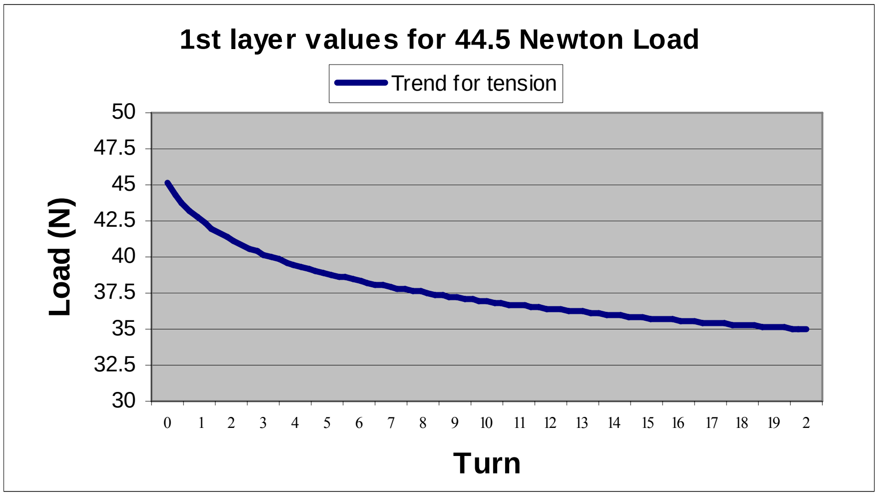


Figure 5.5: 1st Layer 44.5 Newton

Figure 5.5 shows a similar trend to the other graphs plotted as all the experiments are very consistent in showing the same trend. However this particular graph is chosen as a representative because the percentage drop in tension for this graph is the least, and therefore will be the most conservative when used to compute the *tension correction factor.*

It was also observed that whenever a second layer is resting on an existing first layer, the tension decrease of the wire rope is very small. In other words, the tension of the wire at a point will continuously decrease, until a second layer is coiled.

From the graph of Figure 5.5, the tension after 5 turns dropped from 44.5 Newton to 38.9 Newton, which is actually a drop of 13.6% with respect to the load that the rope at the load end is experiencing. In other words, after 5 turns, the tension of the rope at the flange end is only **0.874** F_1, when the load F_1 is 44.5 Newton.

The tension of the rope at the flange end when the number of turns is 5, 10, 15 and 20 are reflected in Table 5.2 below:

Table 5.2: Decrease in tension with the increase in number of turns

Turns	% of drum body covered with rope	Compared to actual loading F_1
0	0%	F_1
5	25%	**0.874** F_1
10	50%	**0.825** F_1
15	75%	**0.797** F_1
20	100%	**0.778** F_1

From Table 5.2, the tension at the flange end drop to **0.778** F_1 after a complete layer had been filled, and the load F_1 is acting at turn 20 which is at the other flange.

The graphs showing the trend for tension drop for different sets of experiments on the mild steel drum winch are presented in the Appendix A.

5.4 DECREASE IN ELONGATION WITH THE INCREASE OF TURNS

The purpose of setting up the second experiment is to verify whether there is any change in elongation as the number of turns increase. The percentage drop in elongation is proportional to the tension drop with all the other factors kept constant.

The trend for the decrease in elongation again shows a rapid decrease for the rope at the flange end when the number of turns are within 5 turns of the winch drum body. Thereafter, the values continue to decreases gradually as the number of turns increases, as reflected clearly in Figure 5.6 below.

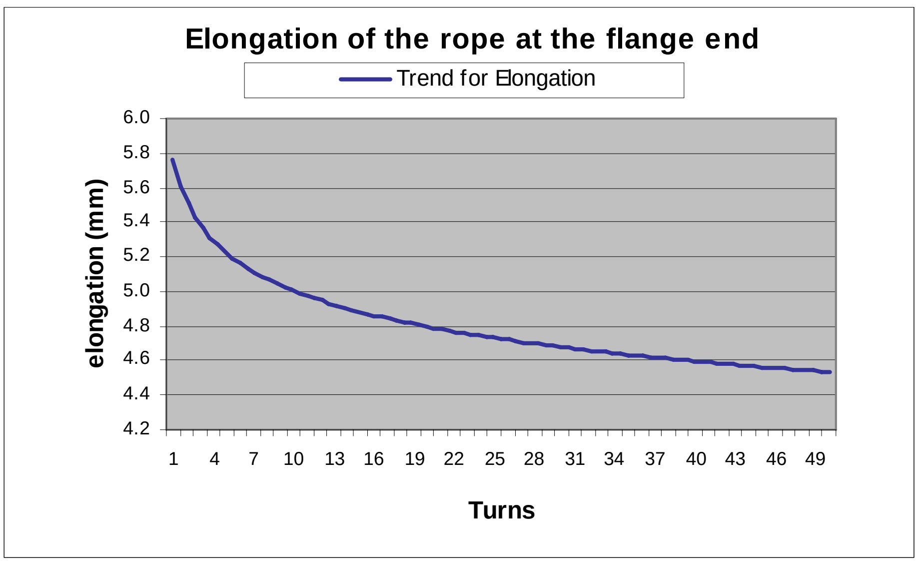


Figure 5.6: 1st Layer 19.6 Newton

For this experiment, the elongation decrease was measured at different points on the drum and not only at the initial flange end. It is interesting to note a high level of consistency for the trend at different points of the drum. In other words, the percentage decrease in elongation after 5 turns from the flange end is very similar to the percentage decrease in elongation after 5 turns from the centre of the winch drum, and thus confirming the validity of the interpretations later.

Figure 5.6 shows the trend for the initial elongation at the flange end as the drum is turned from turn 1 to turn 50. It is representative of the elongation decrease for the rest of the points as the trend is consistent as mentioned in the preceding paragraph.

The percentage decrease of elongation of the fishing line on the acrylic winch drum as compared to the percentage decrease of tension of the wire rope on the mild steel winch drum is shown on Table 5.3.

Table 5.3: Difference in percentage decrease of both experiments

Turns	Tension decrease compared to initial loading, F_1	Elongation decrease compared to initial elongation, E_i
0	F_1	E_i
5	**0.874** F_1	**0.906** E_i
10	**0.825** F_1	**0.868** E_i
15	**0.797** F_1	**0.847** E_i
20	**0.778** F_1	**0.832** E_i

Although there is a difference highlighted in Table 5.3 between the experiments, this difference is actually quite small and is only 6% over 20 turns. However both experiments are consistent to show a sharp decrease followed by a gradual decrease, and thus showing that the assumption of a constant tension all along the ropes in marine winch during coiling operations is not correct.

As the instrumentation used for the mild steel drum was more accurate compared to the manual reading done on the acrylic winch drum, the data shown on Table 5.2 of this chapter will be used in the calculation of the *tension correction factor*. Furthermore the load cell reading measures the tension direct compared to the requirement to use elongation values to obtain tension values for the acrylic winch drum experiment, whereby the accuracy is not so good.

However, as the percentage decrease in the acrylic drum experiment is slightly lesser as depicted on Table 5.3, the author will calculate a more conservative tension correction factor and place it in the Appendix B for reference.

5.5 INTERPRETATIONS

From the trend illustrated earlier in Figure 5.5 as well as other experiments showing consistent results, it can be deduced that the tension along the other points of the drum will also decrease according to this trend. This is further supported by the trends for elongation decrease for the acrylic drum experiment at different portions along the winch drum body.

In other words, after 20 turns have been done for any layer, the initial point will experience a rope tension of **0.778** F_1 whereas a point at the centre of the drum will experience only a decrease equivalent to that of 10 turns which is **0.825** F_1.

Therefore, by flipping the trend line from right to left obtained experimentally in section 5.3, one can obtain the rope tension along the different points of the drum for which the layer is fully coiled. Thus, for a fully coiled layer, the rope at the last turn of the drum will experience the full load F_1.

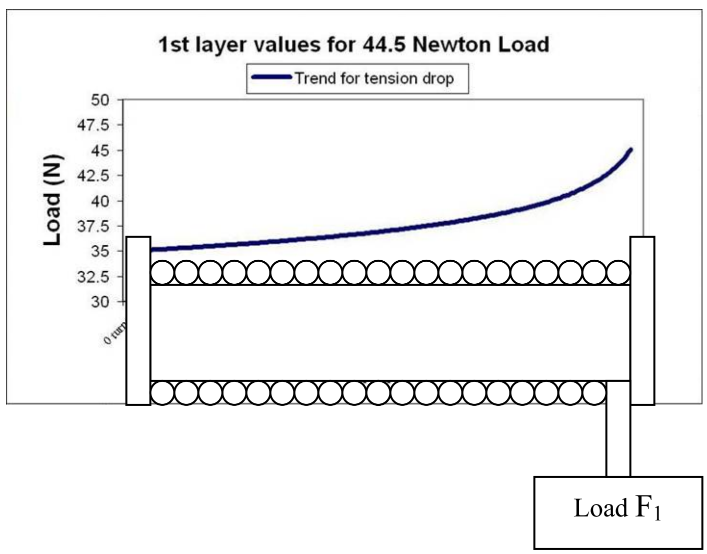


Figure 5.7: Measurement of the tension at all points on the drum

As Figure 5.7 shows, after 20 turns have been completed and one full layer is filled, the various points of the rope will experience different tension; with the rope at the left side having the lowest value **0.778** F_1 and that of the right having the highest of F_1.

5.6 DECREASE IN TENSION WITH THE INCREASE OF LAYERS

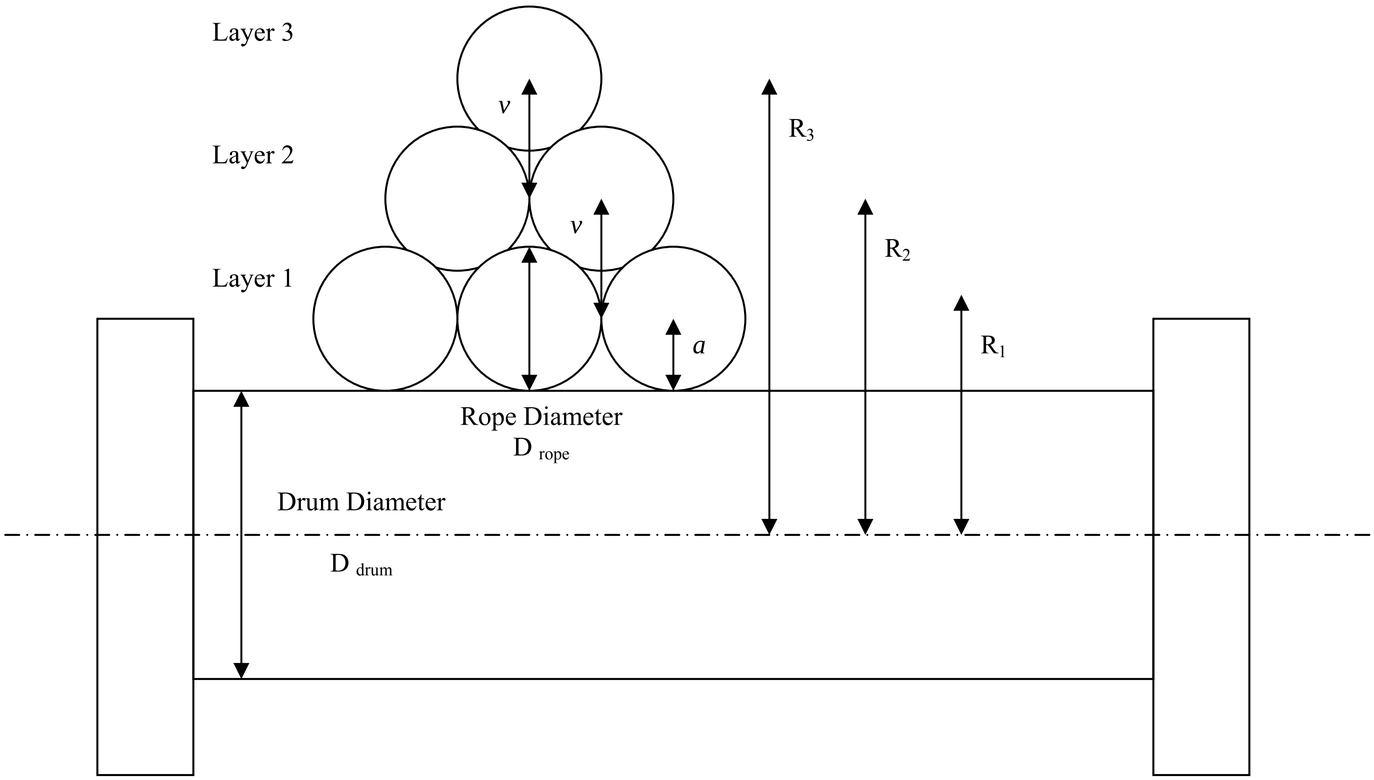


Figure 5.8: Dimensions for Torque Calculation

Nomenclature:

D_{drum} = Drum diameter

D_{rope}= Rope diameter

a = Rope Radius = $D_{rope} / 2$

v = Vertical Distance between the centre of 2 ropes in adjacent layers

R_1 = Vertical Distance from centre of rope of layer 1 to the centre of Drum

R_2 = Vertical Distance from centre of rope of layer 2 to the centre of Drum

R_3 = Vertical Distance from centre of rope of layer 3 to the centre of Drum

R_N = Vertical Distance from centre of rope of layer N to the centre of Drum

From Figure 5.8,

$R_1 = D_{drum}/2 + a$

$R_2 = D_{drum}/2 + a + v$

$R_3 = D_{drum}/2 + a + 2v$

$R_N = D_{drum}/2 + a + (n\text{-}1)\,v$

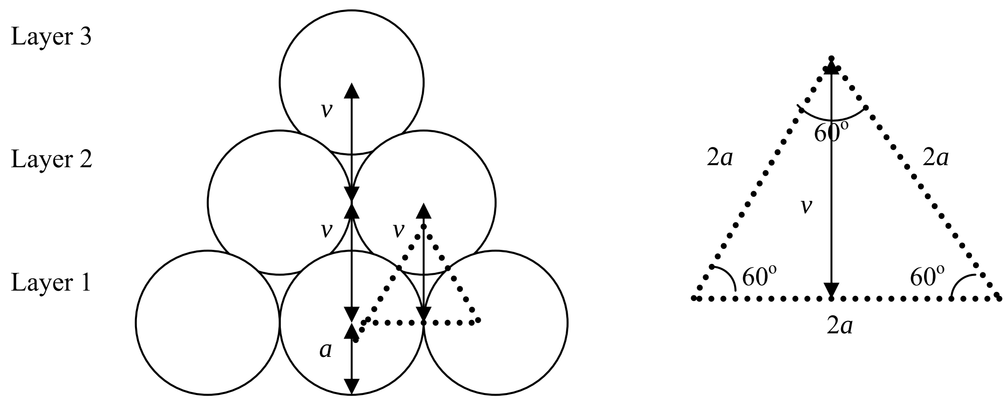


Figure 5.9: Relating *v* value to *a* value

From Figure 5.9,

$$\sin 60^0 = \frac{v}{2a}$$

$$v = 2a \times \sin 60^0 = 1.732a$$

Rewriting,

$R_1 = D_{drum}/2 + a$

$R_2 = D_{drum}/2 + 2.732a$

$R_3 = D_{drum}/2 + 4.464a$

$R_N = D_{drum}/2 + a + (n-1) \times (1.732a)$

For the operations in marine winches, there is a limiting load that the winch can take based on the torque supplied by the motor.

Assuming a fixed maximum torque **T =** $F_N \times R_N$, where

F_N is the load at layer N and

R_N is the vertical distance from the centre of rope of layer N to the centre of drum.

Since the operating torque is constant,

$F_N \times R_N = F_1 \times R_1 = F_2 \times R_2 = F_3 \times R_3$

Therefore the tension of each layer of rope is related to the tension of the rope when applied in the first layer by the following relation:

$$F_N = \frac{R_1}{R_N} \cdot F_1$$

Substituting the results obtained from above,

$$F_N = \frac{D_{drum}/2 + a}{D_{drum}/2 + a + (n-1)\cdot(1.732a)} \cdot F_1$$

Simplifying

$$F_N = \frac{D_{drum} + 2a}{D_{drum} + 2a + (n-1)\cdot(3.464a)} \cdot F_1$$

Where n = 2, 3, 4, 5 … last layer

Observing that the numerator is always smaller than the denominator, it is concluded that the fixed maximum torque causes the tension to *decrease* as the number of layers *increase*. This relation depends on the dimensions of the drum winch and rope used.

For the experiment using the mild steel drum winch,

The drum diameter, D_{drum} is 200 mm

The rope diameter D_{rope} is 5mm and

The rope radius $a = D_{rope} / 2$ is 2.5mm

The computed tensions for layer 2 and layer 5 compared to the tension in layer 1 are as follows:

Table 5.4: Decrease in tension with the increase in Rope Layers

Layer	Tension	Compared to tension in layer 1
2	F_2	**0.959** F_1
3	F_3	**0.922** F_1
4	F_4	**0.888** F_1
5	F_5	**0.855** F_1

As mentioned earlier, the ratio between tension values may differ depending on drum geometry. The ratio for the acrylic drum geometry is tabulated in Appendix B as an example of a drum with a different geometry.

5.7 CALCULATION OF TENSION CORRECTION FACTOR

As illustrated in section 5.5 and section 5.6 of this chapter, the tension exerted by the rope on the drum is decreasing with the increase in the number of turns within the same layer as well as with the increase in the number of layers.

The decrease in the tension on the wires compared to the initial load F_1 are again highlighted in Table 5.5a and Table 5.5b below, of which are important for the computation of the *tension correction factor*.

Table 5.5a: Turn factor T_f

Turns	Turn Factor T_f
0	1
5	**0.874**
10	**0.825**
15	**0.797**
20	**0.778**

Table 5.5b: Layer factor L_f

Layer	Layer factor L_f
2	**0.959**
3	**0.922**
4	**0.888**
5	**0.855**

The decrease in tension along the drum with the increase in turns will be termed *turn factor* T_f and the decrease in tension with the increase in number of layers will be termed *layer factor* L_f for convenience of presentation. The T_f and L_f factors will vary at different points of the drum and at different stage of the whole coiling process and their values are from Table 5.5a and Table 5.5b.

For the **first layer** of rope, the *tension correction factor* will not be affected by the layer factor as the load is applied at the first layer and the operating constant torque does not result in a reduction in tension applied. The *tension correction factor* will also not be affected by the turn factor as the worst case scenario occurs when the load is applied at the point of interest. And when that is the case, the point of interest will be taking the full load and there will be no drop in tension due to the increase in turns. In fact, for the calculation of the *tension correction factor* for all the outermost layers will not involve the turn factor. Being conservative, this will cater for the worst case scenario.

For the **second layer** of rope, the total tension acting at any point will be the turn factor for layer 1 plus the layer factor of layer 2. The *tension correction factor* will be computed by dividing the total tension by 2 F_1. The *tension correction factor* helps to scale down any overestimate resulting from assuming equal tension of the wire at different parts and stages of coiling.

For the **third layer** of rope, the total tension acting at any point will be the turn factor for layer 1 plus the layer factor of layer 2 multiply by the turn factor plus the layer factor of layer 3. The *tension correction factor* will be computed by dividing the total tension by 3 F_1. The *tension correction factor* for the subsequent layers and points are calculated in the same manner.

The calculation of the *tension correction factor* will be explained with the aid of Figure 5.10. The point of interest Point B is at the point of turn number 5 counting from the left of the drum. The first layer is coiled from left to right. The second layer is from right to left. It goes on in this manner. The coiling method is the same for all the calculations.

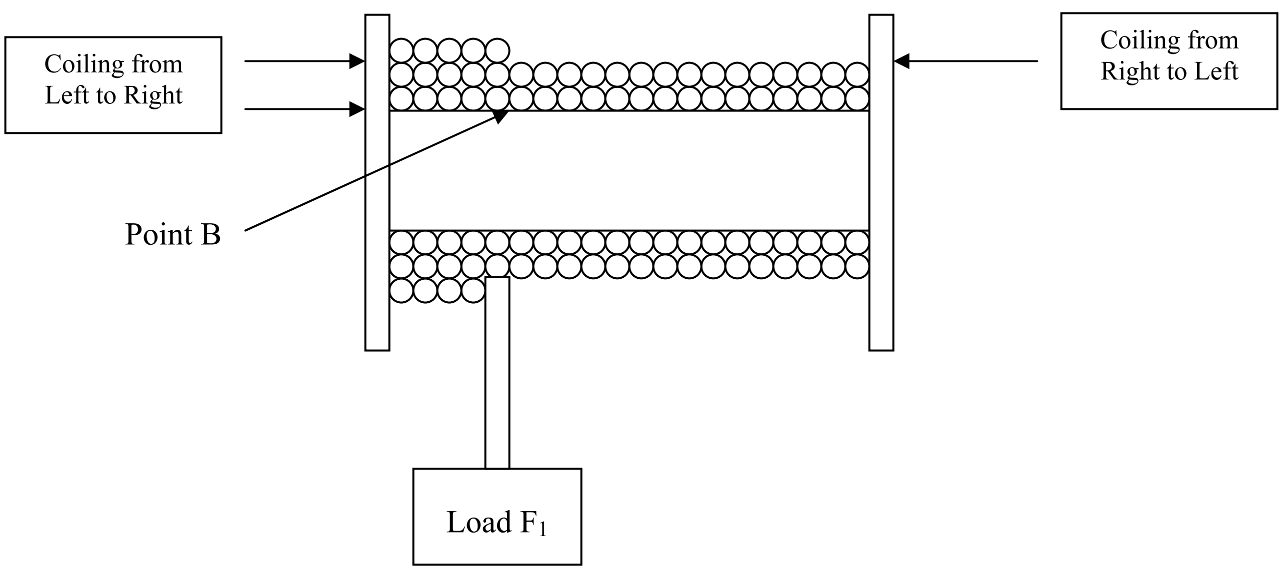


Figure 5.10: Total Tension at Point B

The tension at Point B is a result of the tension by the three layers of ropes on top of the point:

The tension because of Layer 1 rope is **0.797** F_1 because there are 15 turns between Point B and the right flange. According to Table 5.5a, the rope tension drops to **0.797** F_1 after 15 turns and will remain so once the second layer goes on top of layer 1.

The tension because of Layer 2 rope is equal to the layer factor of layer 2, L_f multiply by the turn factor T_f (**0.959**) x **0.874** F_1 = **0.838** F_1. The turn factor is now **0.874** because there are 5 turns between Point B and the left flange. According to Table 5.5a, the rope tension drops to **0.874** F_1 after 5 turns and will remain so once the next layer goes on top of the existing one.

The tension because of Layer 3 rope is layer factor of layer 3, L_f which is (**0.922**) F_1. There is no turn factor involved as the worst case scenario occurs when the load F_1 is acting directly above the point.

The total tension is then the sum of **0.797** F_1, **0.838** F_1 and **0.922** F_1; which is **2.557** F_1. The *tension correction factor* is then **2.557** F_1./ **3**F_1. = **<u>0.852</u>**.

Figure 5.11 shows the points of interest, Point A, Point B, Point C, Point D and Point E along the length of the drum. Point A is the point on the left, where the coiling begins for the first layer.

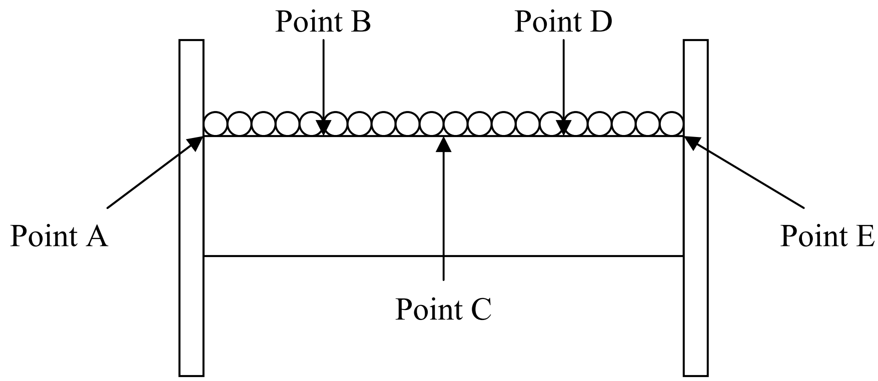


Figure 5.11: The points of interest

Using the above methodology for calculating the *tension correction factor* at Point B after coiling 3 layers of ropes, the *tension correction factor* is computed and presented in Table 5.6 below for Layer 3 at the different points of interest.

Table 5.6: Tension correction factor for Layer 3

Layer	Point	Tension correction factor P_{JE}
3	A	0.886
	B	0.852
	C	0.846
	D	0.853
	E	**0.889**

Point E appears to have the least drop in Tension and having the highest *tension correction factor*. Being conservative, this will be the selected as the *tension correction factor* representative for that layer. The representative *tension correction factor*s for the other layers are presented in Table 5.7.

Table 5.7: Tension correction factor for 5 layers

Layer	Tension correction factor P_{JE}
1	**1**
2	**0.980**
3	**0.889**
4	**0.889**
5	**0.843**

The *tension correction factor* has shown that the assumption of a constant rope tension is an over-conservative assumption and the computations of it at all points on the drum and at all 5 layers can be done and will be useful to analyze the relevant design code.

Although the *tension correction factor* does not sufficiently explain everything about the relevant design guides, it will still be interesting to compute a revised rope layer factor K* using the *tension correction factor* P_{JE} multiply by the original rope layer factor K for the SAA guide, for comparison purpose.

Table 5.8: Revised Rope Layer Factor K*

Layer	Original Rope Layer Factor K	Revised Rope Layer Factor K*
1	1.0	**1.00**
2	1.3	**1.27**
3	1.5	**1.33**
4	1.6	**1.42**

CHAPTER 6: CONCLUSIONS

As the experimental results have shown consistently and repeatedly, it is incorrect to assume uniform rope tension experienced by wire ropes when it is coiled using a winch drum.

The experimental results obtained for the trend of tension decrease showed that the tension experienced by the ropes do decrease with the increase in the number of turns within a layer as well with the increase in the number of layers.

These experimental results were used to obtain the *tension correction factor* P_{JE} which helps to improve upon the inadequacy of the relevant guides, by scaling down on any possible over-design as a result of the assumed uniform tension.

The empirical results are also useful to locate and calculate the force exerted by wire ropes on different parts of the drum winch body at different stages of coiling. With these available data, more can be done using the FEM software to obtain more analysis to enhance the present design guides.

Personally, the Final Year Project had been a thoroughly enriching and fruitful journey of learning, and it gives me the opportunity to apply classroom lessons, in a practical situation. The FYP had sharpened my analytical and practical skills and will be an invaluable asset in my future endeavors.

CHAPTER 7: FURTHER IMPROVEMENTS

To improve upon the current project, the most important is to verify the validity of the tension decrease in wire ropes in actual marine winch operations. The site testing at Plimsoll Cooperation Pte Ltd is necessary to confirm the trend of tension decrease done on the miniature mild steel and acrylic drums. For the site testing, strain gauges can also be placed on the drum body to obtain directly, the strain experienced by the winch drum.

Another improvement that can be done is to use a strain meter that does not fluctuate too much, to obtain a more precise strain value for the mild steel winch drum.

Besides the improvements to the winch drum code to reduce the thickness of the winch drum, materials and operations costs can be reduced by altering the present shaft design of winch drums. Presently, the marine winch drum uses a shaft through the entire length of the drum to transmit power to drive the coiling processes. Studies can be done into the coupling used during the coiling process and investigate whether there is a need to have such a long shaft.

Figure 7.1: The shafts used

<u>REFERENCES</u>

[1] Serway, R.A., & Beichner, R.J. (2000). Physics for Scientists and Engineers, Chapter 10, *Rotation of a Rigid Object around a fixed axis* (pp 306-307)

[2] Baker, E.H., Kovalevsky, L., & Rish, F.L. (). Structural Analysis of Shells, Chapter 5, *Special solutions* (page 107)

[3] Standards Association of Australia: A.S No CB.2 – 1960 : [part 5.25]

[4] Det Norske Veritas: Section 5 Machinery and Equipment : [part 206, 207]

[5] http://www.plimsollcorp.com

APPENDIX A

This section will contain the experimental results obtained for the mild steel drum winch experiments, as well as the calculations based on these individual sets of experiments.

Figure A1 to A5 shows the trends for the various experiments conducted using the mild steel winch drum containing different loads, carried out on different dates:

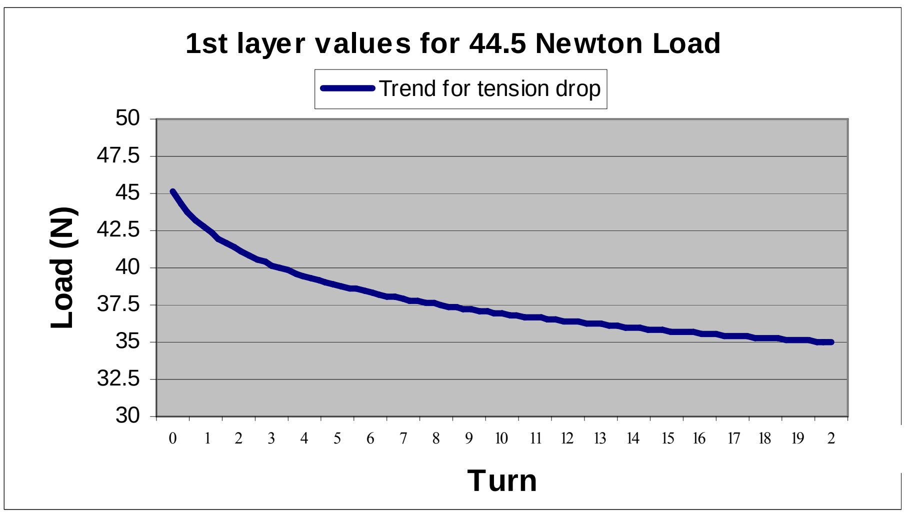


Figure A1: 12 October Data: 1st Layer 44.5 Newton

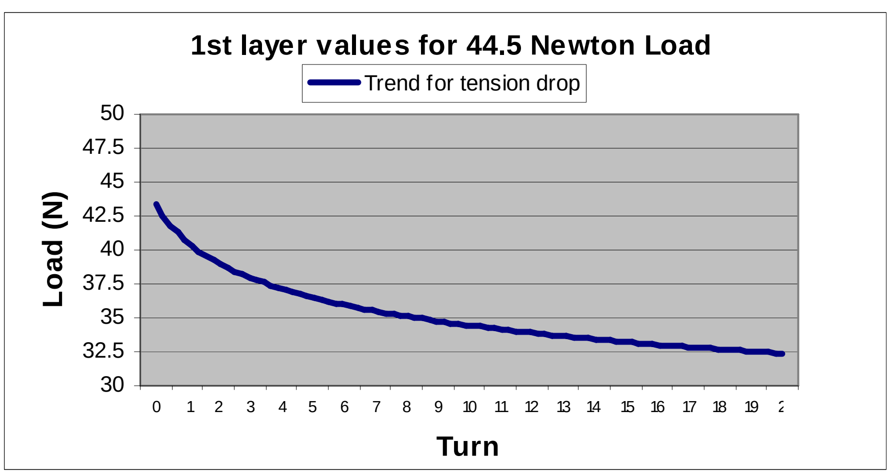


Figure A2: 10 October Data: 1st Layer 44.5 Newton

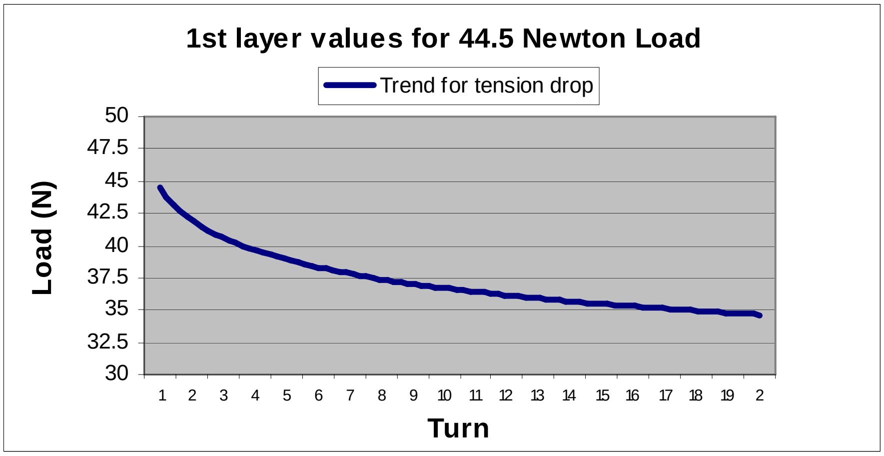


Figure A3: 17 October Data: 1st Layer 44.5 Newton

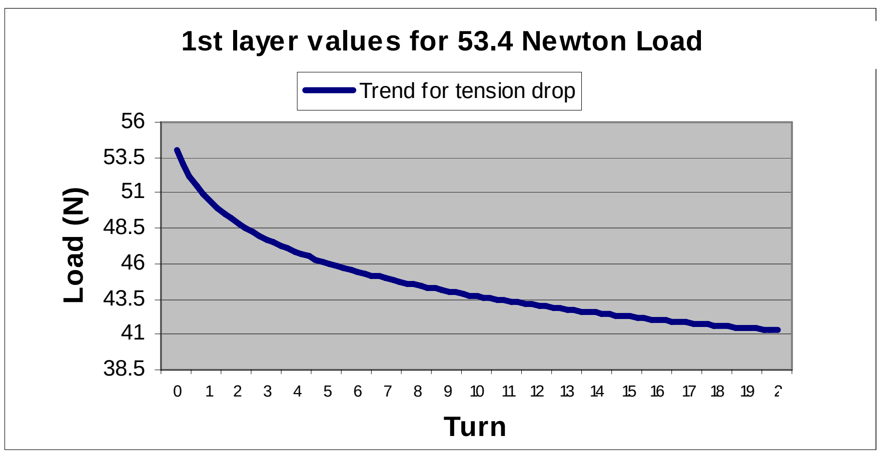


Figure A4: 12 October Data: 1st Layer 53.4 Newton

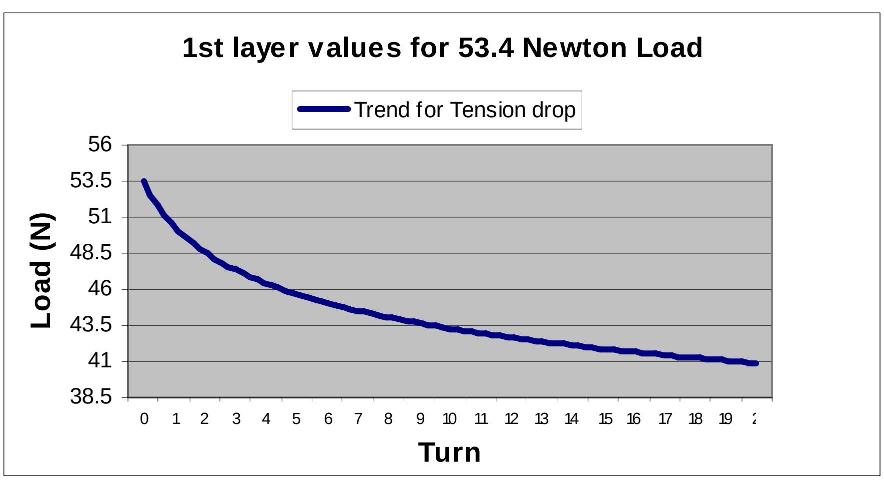


Figure A5: 10 October Data: 1st Layer 53.4 Newton

As mentioned in the main report, the graph for Figure A1 was chosen for further analysis because it showed the least percentage drop in tension values and was deemed the most conservative. Table A1 below compares the difference in values for percentage for the different experiments, with the representative one used in the main report, highlighted below in bold.

Table A1: Comparison of tension drop for various experiments

Turns	Figure A1	Figure A2	Figure A3	Figure A4	Figure A5
0	F_1	F_1	F_1	F_1	F_1
5	**0.874** F_1	0.856 F_1	0.874 F_1	0.868 F_1	0.867 F_1
10	**0.825** F_1	0.801 F_1	0.824 F_1	0.8817 F_1	0.815 F_1
15	**0.797** F_1	0.770 F_1	0.797 F_1	0.788 F_1	0.786 F_1
20	**0.778** F_1	0.749 F_1	0.778 F_1	0.768 F_1	0.766 F_1

In other words, Table A1 above actually compares the Turn factor T_f of the different experiments, which is required to calculate the final tension correction factor.

Table A2: Layer factor L_f

Layer	Layer factor L_f
2	**0.959**
3	**0.922**
4	**0.888**
5	**0.855**

Table A2 shows the other important component for the calculation of the tension correction factor, which is the table for the layer factor L_f. This table works for Figure A1 to Figure A5 as all the experiments were carried out on the same drum and thus has same dimensions, and the layer factor is only affected by the dimensions of the drums.

The tension correction factor will not be calculated for the other Figures besides the representative one shown in the main report as the others are less conservative figures and does not represent the worst case scenario.

APPENDIX B

This section will contain the results obtained for the acrylic winch experiments and detail the calculations based on this part of the experiment..

Figure B1 shows the trend for the various experiments conducted using the acrylic winch drum and the Table B1 shows its turn factors:

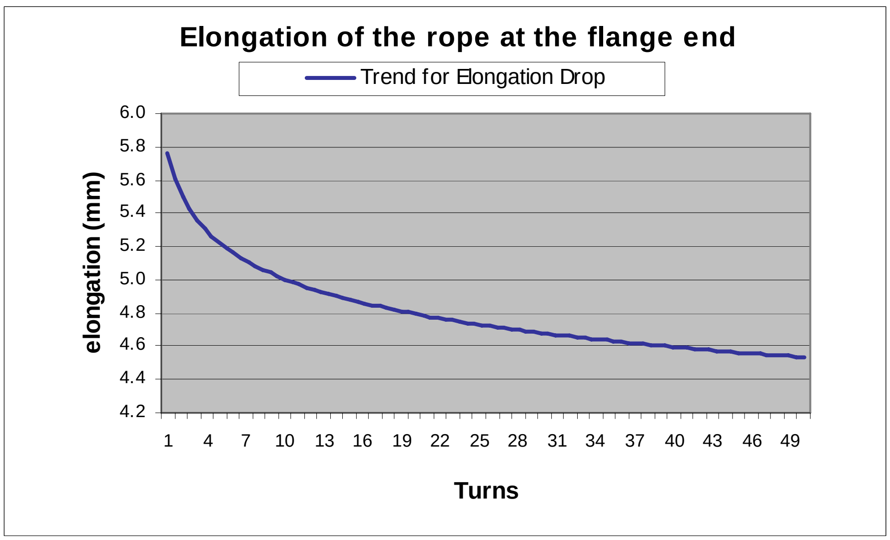


Figure B1: 14 February Data: 1st Layer 19.6 Newton

Table B1: Turn factor T_f for acrylic drum winch

Turns	Turn Factor T_f
0	1
5	**0.906**
10	**0.868**
15	**0.847**
20	**0.832**

The layer factor calculations based on the dimensions of the acrylic winch drum is reflected on Table B2.

Table B2: Layer factor L_f for acrylic drum

Layer	Layer factor L_f
2	**0.983**
3	**0.967**
4	**0.951**
5	**0.936**

Using the methodology explained in the main report, the tension correction factor for this set of experiment is calculated and shown in Table B3 below.

Table B3: Tension correction factor for acrylic drum

Layer	Tension correction factor P_{JE}
1	**1**
2	**0.992**
3	**0.928**
4	**0.934**
5	**0.902**

As mentioned earlier, though this set of tension correction factor is more conservative, it is not used in the main report as the instrumentation and accuracy of the mild steel winch drum experiment was better.

APPENDIX C

Figure C1 and Figure C2 are the engineering drawing and the final product of the mild steel winch drum fabricated for the first part of the experiment.

Figure C1: Engineering drawing of the mild steel winch drum

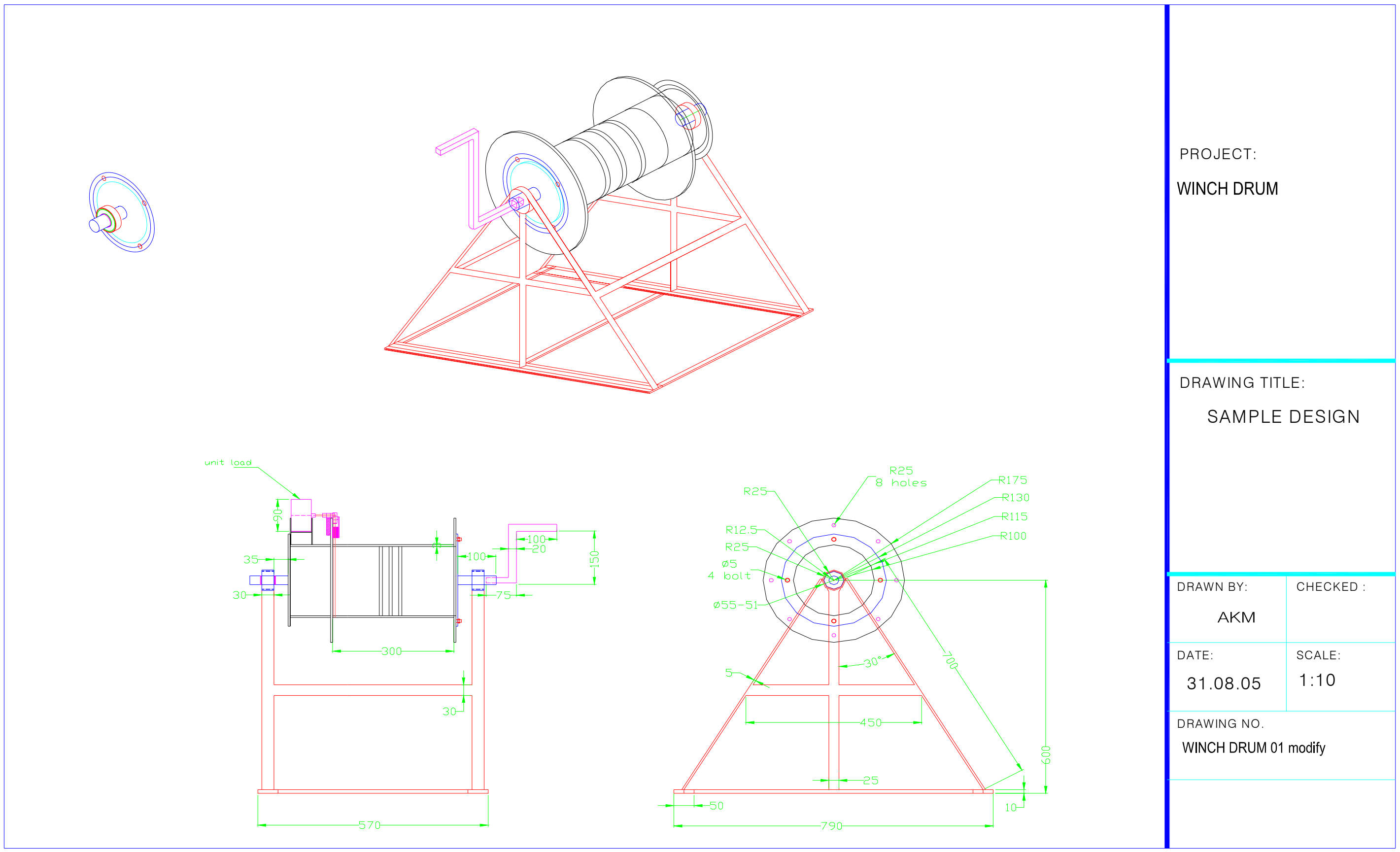


Figure C2: Final Product of the mild steel winch drum

APPENDIX D

The following information is further analysis done on the project with regards to the stress, the deflection for a drum winch unless increasing pressure. The formulas used to plot these graphs are also attached.

Formula using for plotting graph

Reference Book Title: Structural Analysis of Shells

Authors: E.H, Baker, L. Kovalevsky, F.L. Rish

Text: Chapter 5, Special solutions (page 107)

Stress: $N_\theta = \frac{Et}{R}\left[w_p(\xi) + S_1 F_7(\xi) + S_2 F_{15}(\xi) + S_3 F_{16}(\xi) + S_4 F_8(\xi)\right]$,

Deflection: $w = w_p(\xi) + S_1 F_7(\xi) + S_2 F_{15}(\xi) + S_3 F_{16}(\xi) + S_4 F_8(\xi)$

$\xi = \frac{x}{L}$, $k = \frac{\sqrt[4]{3(1-\nu^2)}}{\sqrt{Rt}}$

$w_p(\xi) = \frac{P_v R^2}{Et}(1-\xi)$, $S_1 = -\frac{P_v R^2}{Et}$, $S_2 = -\frac{P_v R^2}{Et}\left[\frac{F_3}{F_1} - \frac{1}{kL}\left(\frac{F_6}{F_1} + \frac{F_8}{F_1}\right)\right]$

$S_3 = +\frac{P_v R^2}{Et}\left[\frac{F_3}{F_1} - \frac{1}{kL}\frac{F_5}{F_1} + \frac{F_8}{F_1}\right]$, $S_4 = +\frac{P_v R^2}{Et}\left[\frac{F_2}{F_1} - \frac{1}{kL}\left(\frac{F_4}{F_1} + \frac{F_9}{F_1}\right)\right]$

$F_1 =$ $\sinh^2 kL - \sin^2 kL$

$F_2 =$ $\sinh^2 kL + \sin^2 kL$

$F_3 =$ $\sinh kL \cosh kL + \sin kL \cos kL$

$F_4 =$ $\sinh kL \cosh kL - \sin kL \cos kL$

$F_5 =$ $\sin^2 kL$

$F_6 =$ $\sinh^2 kL$

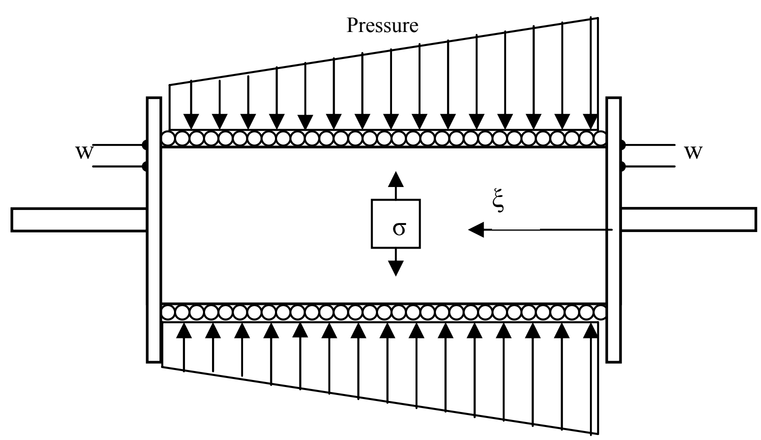
$F_7 =$ $\cosh kL\xi \cos kL\xi$

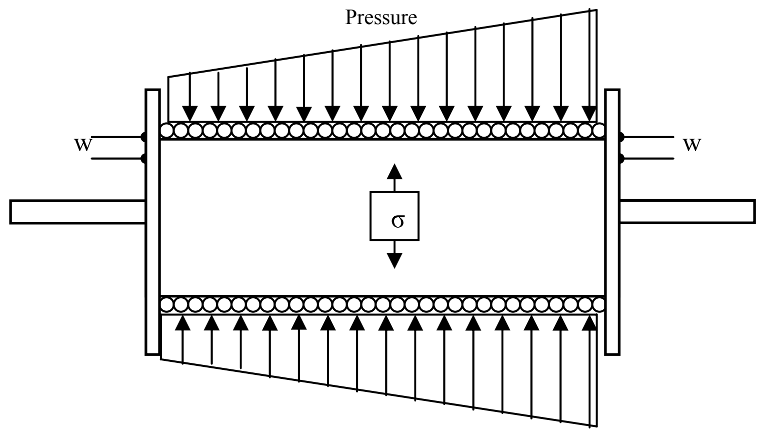
$F_8 =$ $\sinh kL\xi \sin kL\xi$

$F_9 =$ $\cosh kL\xi \sin kL\xi - \sinh kL\xi \cos kL\xi$

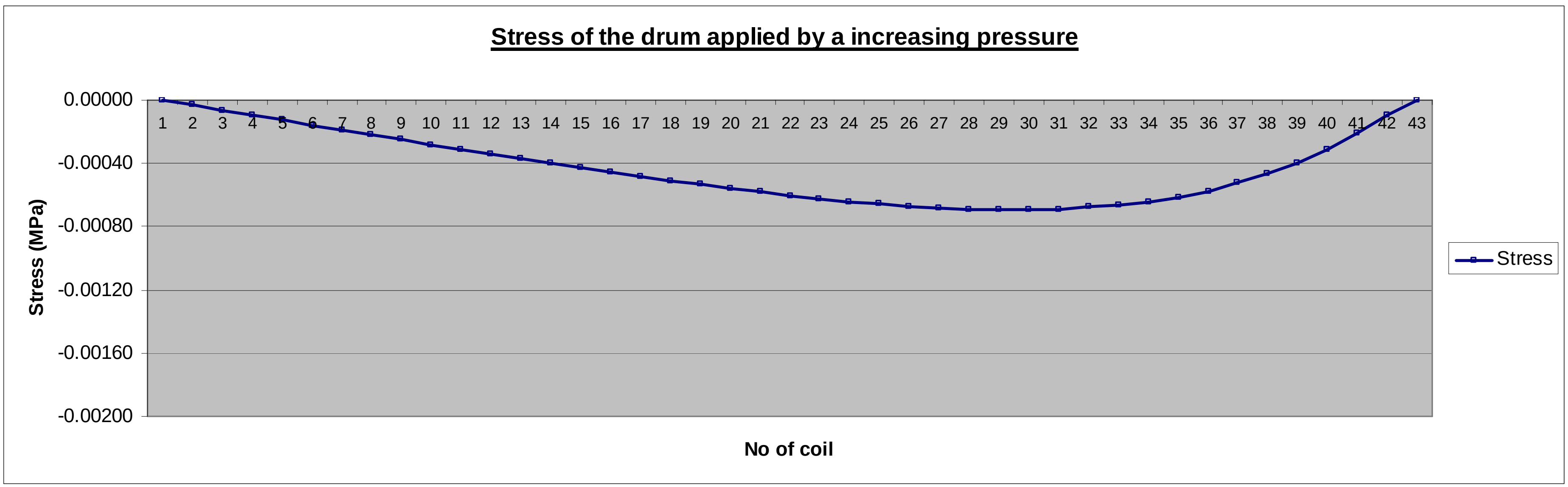
$F_{15} =$ $\cosh kL\xi \sin kL\xi$

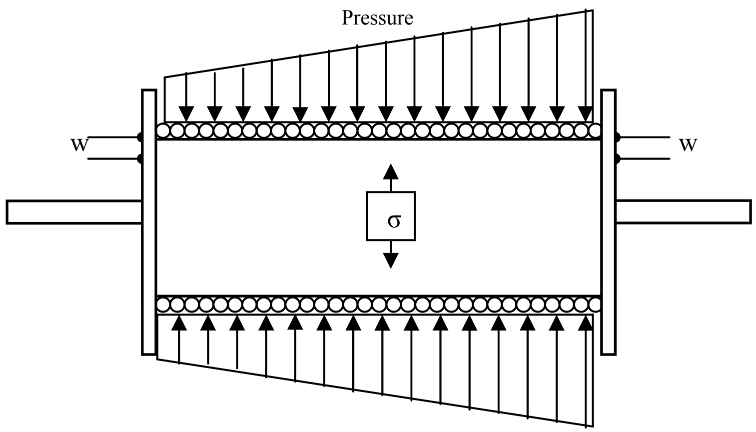
$F_{16} =$ $\sinh kL\xi \cos kL\xi$





Stress acting on the right side of the drum after coiling fulllength of drum.





Deflection of the drum under increasing pressure beneath of on each coil.