Appendix I: Example of Student Work

Submission for Course Assignment 1: Ecolos Cable Ferry Failure

Introduction

This section of the report will summarize the information regarding the failure of the *Ecolos* Ferry. This will include information provided by the preliminary report with regards to why and how the ferry failed, background information, and all information used to model the scenario.

On December 9th, 2010, the *Ecolos* Ferry experienced cable failures in its last crossing of the year from Thurso, Quebec to Rockland, Ontario. At 8:45PM on that day, three cable failures occurred due to an assumed lateral force on the cable that was beyond its breaking force. Abnormal weather conditions were noticed that week, and may have contributed to the eventual failure of the cable. Environment Canada recorded a temperature of -15°C, down from the previous week's temperature of -5.7°C. Additionally, the average daily river water temperature fell from 2.8°C on the 5th of December to 0.5°C on the 9th of December (the day of the cable failures). These factors led to the additional, unusual formation of ice, which eventually led to the accident happening. To support the above data indicating additional ice formation, large ice floes were noted drifting down the river. Landfast ice was also noted along the shore, and it, together with the floating ice pans and slush were reported to cover approximately 90% of the river surface.

The ferry was tethered to shore on both sides by 2 1-inch diameter 6x36 IWRC PFV grade steel cables. A public relations representative from the cable company reported that the cable had a breaking force of 100,000 pounds. The cables had an expected operating load of 3,100 pounds per cable, and in the case that one cable failed and the system was operating on one cable only, an expected operating strength of 6200 pounds.

Human error was proved to be a factor in the ferry's cable failure as well. The Preliminary Investigation Team Report outlined the poor condition of the Eastern cable, noting that it was showing extensive wear, had complete loss of galvanization, and had several broken strands. Supposedly, the cable was to be checked every week, but the TSB Preliminary Onsite Assessment Team reported the cable to be at approximately 25% of its original strength, with noticeable visual deterioration at the time of the accident.

Uncertainties and biases should be taken into account when dealing with the aforementioned information. Firstly, the public relations officer will have a bias towards the cable company they represents so there is a motive to overstate the breaking force of the cable to make the cable seem stronger and more reliable. Another uncertainty lies in the strength of the cable. No information is known regarding whether or not the cable was replaced prior to the 2011 season with the exception that there was a scheduled replacement at that time. Also, properties of the cable (breaking point, elasticity modulus) might have been altered due to prior plastic deformation of the cable. If the tension on the cable exceeded half of its breaking strength at any point after its last replacement, the cable would have exhibited plastic behaviour and experienced permanent damage, thus weakening the cable. If this is the case, then the reported value for the breaking strength of the cable would be inaccurate and an additional model would be needed to determine the damage done to the cable and its breaking strength as a result.

The models used to represent the cable failure depend on the understanding of multiple physics concepts. The first model has a heavy reliance on the concepts associated with Newtonian forces, and specifically, drag forces (both surface and form drag forces. The second model requires knowledge of plastics and elastics, as plastic deformation begins at a certain value of stress (in this case, 50% of the tensile breaking strength

Process

This report will analyse and review possible causes, solutions and risk analysis for the Ecolos electric cable ferry failure on December 09 2010. Before the data can be analysed, all possible causes must be determined, stakeholders must be questioned, and tests/measurements must be conducted. Then, once this investigation is complete, a model can be made to ultimately decide what exactly caused the Ecolos ferry's failure.

The investigation that will be conducted will follow a general process weather analysis, questioning stakeholders, and taking needed measurements and tests of the ferry and surrounding area. By comparing weather conditions, it can be determined how out of the ordinary the weather was on the day of the incident and if the fault was due to extreme climate. If stakeholders such as the ferry owners, operators, and crewmembers are questioned, additional data that may be important to our investigation can be revealed. Despite the best efforts of the preliminary investigative team, there are still many aspects of the incident that are unaccounted for. By taking new measurements and tests of the ferry, valuable insight into the root cause of the ferry's failure can be gained. If this general investigation process is followed, the cause of this dangerous accident can be determined.

The first task of the investigation is to analyse the current and average weather conditions then compare those to the weather the day of the incident. If the weather on December 9th is significantly more extreme than average; the failure of the ferry can be accredited partly to the harsh weather. According to the preliminary report the weather the day of the failure had a wind speed of 15km/h, river speed of 1.2 knots and a water temperature of 0.5 degrees Celsius. Each of these values when viewed alone may seem to have a minor effect on the ferry but, when added together the force may have been great enough to cause the cable failures. If the average weather on the Ottawa were much less than on the day of the accident then it is likely that the ferry manufactures would not have accommodated for forces that strong pushing against the ferry.

To determine the forces that acted upon the ferry at the time of breaking, many different aspects of the system must be considered. The forces acting laterally upon the ferry include the force cause by wind, water and ice. The force of water acting upon the ferry only comes in contact with the portion of the ship under water or the draught. Given to us by the preliminary report is the ferry's side length, draught and average water speed. The water speed given to s was an average speed on that day but speed of water varies with regard to depth of water. The speed of water at the specific depth the ferry failed at would need to be determined. Finding the average speed of the river on our investigation day and comparing it to the speed of water at the specified distance across river could find this. Then a ratio can be formed to solve for the speed of water on December 9th at that specific distance across the river. With the exact speed of water at this the specified depth of river, a more accurate force of water acting upon the ferry can be determined.

The force of ice is more difficult and complicated to calculate than the force of water, to determine the force of ice the ice thickness, speed of river, surface area of boat exposed to ice pressures, and the rate at which the ice is accumulating against the side of the ferry are all needed values. The preliminary report supplied gives the values for most of those factors but leaves out the rate at which new ice is forming and being brought down from up stream. An investigation into the rate at which ice accumulates must be held. Once this value is determined a general estimate can be made as to how much force with respect to time the ice was applying laterally against the ferry. To determine the force the wind applies against the side of the ferry the surface area exposed to the wind must be determined. Although the preliminary report gives the value for length it lacks the value for the height of the ferry. During the investigation the varying height of the ferry must be measured and recorded so that the force of wind applied can be appropriately determined.

For an incident like this to occur some factor or variable in the ferry's journey must have been unaccounted for or unexpected. Many system failures are often due to a designer overlooking or underestimating the effects the environment can have on a system. To determine if certain conditions may have been overlooked the stakeholders must be questioned with regards to how and why the ferry was built the way it was. One thing that the preliminary report observed was that the east cable condition was relatively poor on the day of the failure. It was reported that the tensile strength of the cable was approximately 25% less than what it is on when first manufactured. This loss in strength was due to the complete loss of galvanization and the fraying/fracturing of all 10 outer wires on each strand. The question for the owner of this ferry would be: why, despite the clear damage to the east cable and obvious weather conditions, was the ferry operating on December 9th 2012? If this question cannot be answered than the safety rules and regulations of this company must be altered to prevent a similar accident from occurring in the future.

Besides environmental issues there are also other factors that may have cause the ferry failure. During our investigation all pulleys and motors should be accounted for and analysed to see if they may be affecting the strength of the cable. If the cables are passing through the motor or pulleys on an angle then excess friction will cause heat, which can lead to fraying and severing of the strands in the cable. To assess these possible flaws the ferry manufacturers should be contacted and design papers can be viewed to look for faults in the design. If the ferry cannot withstand these relatively average weather conditions than perhaps the design of the ferry should be altered. Other alternative methods of travel should also be looked into until a better and safer method of crossing the river is plausible.

Despite the cost of replacing cables, pulleys, and redesigning the ferry, this accident could have been much worse. If the ferry had not stayed tethered to land by the west cable, it would have continued downstream breaking through everything it came into contact with; this worst-case scenario would cause millions of dollars in damage, and would likely cause major injury or death. The only thing stopping this failure from becoming a major catastrophe was the single west wire that didn't fracture. The fact that this was so close to be so much worse shows that the safety protocol and maintenance checks needs to be improved. Not only were the passenger's lives at stake, but the surrounding area's residents were at risk as well.

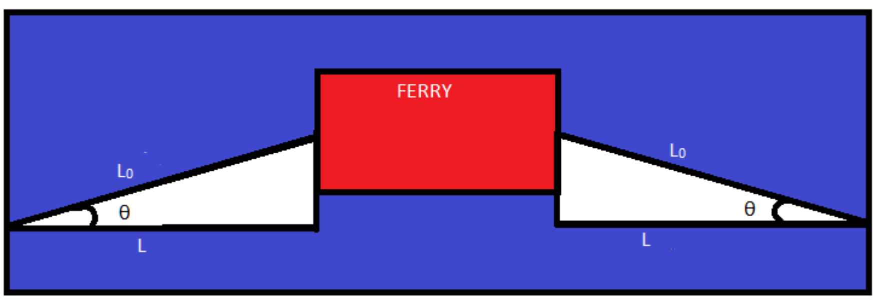
Had this ferry collided with another boat or dock downstream then major damage to property and injury to citizens may have occurred. If the captain had known the weather was unsuitable and the cable weakened then the ship should have stayed ashore and waited for ideal conditions.

If this investigation is followed then all data on ferry will be found, accurate environmental forces can be determined, and all stakeholders will be questioned. Once the investigation is complete a more accurate and specific model can be created with minimal error. With a model made the cause of the Ecolos ferry's failure on the 9th of December 2010 can be determined and prevented in the future.

Models

The following section will discuss the simple model of the Ecolos ferry failure. This section will include the reasoning, equations, and graph of the MATLAB model created. This first model analyses the force of tension on the cable with respect to the angle that the cable makes with the horizontal. It was found that the angle of the cable could be related to the tension present by the use of trigonometry and equations for force. An image of the scenario can be seen in figure 1

Figure 1: diagram of simple MATLAB model scenario.



In figure 1(left) a model of the Ecolos ferry is seen as a force is applied against it causes the cables to stretch and the angle of the cable to the wall to increase. The first model is based on the mathematics of the angle between the cable's new direction and it's original direction, where L_0 is the final position of the cable after a force has been applied, L is the length of the cable at its normal operating position and θ is the angle at which the cable makes with the shore. With Figure 1 a trigonometric relationship between θ, L_0 and L can be seen, as shown in equation 1.

$$cos\theta = \frac{L}{L_0} \quad (1)$$

In the model it was decided to vary the angle that the model makes with the wall from 0 to 6 degrees. θ was set as the independent variable since it is necessary to analyze at what point the tension broke. Rearranging equation 1 for the original length gives the equation:

$$L_0 = \frac{L}{cos\theta} \quad (2)$$

With an equation for the final position, a relationship betweenL_0 and T can be determined. If the cable is stretching as the angle changes then it can be said that the cable is behaving as an elastic material. This means that if a stress under the cable's elastic limit is applied to the cable , then the cable will return to its original shape once stress is removed. If the tension of the cable surpasses the elastic limit than it will not return to its original shape. If surpasses this limit by a large amount, the cable may break. Since the cable is acting as an elastic material, equation (3) can be used.

$$T = EA\frac{\Delta L}{L} \qquad (3)$$

Where T is the tension present on the cable, E is the modulus of elasticity, A is the cross sectional area of the cable (2π multiplied by the radius of the cable), and ΔL is the change in the length of the cable.

Rearranging equation (3) for equation (4), then substituting equation (2) into equation (4) gives the following relationship:

$$T = EA(\frac{L_0 - L}{L}) \qquad (4)$$

$$T = EA\ (\frac{\frac{L}{cos\theta} - L}{L}) \qquad (5)$$

With an equation for tension the model is near completion. To find a range of tension values for the cable it was decided to vary the angle the cable makes with the wall from 0 to 6 degrees (0 to 0.1 radians). If tension as a function of θ is plotted, with the cable's breaking strength and 25% breaking strength it can be seen at what point the cable would have failed. Figure 2 shows the relationship between θ and tension.

Figure 2: Relationship between angle of the cable to its tension.

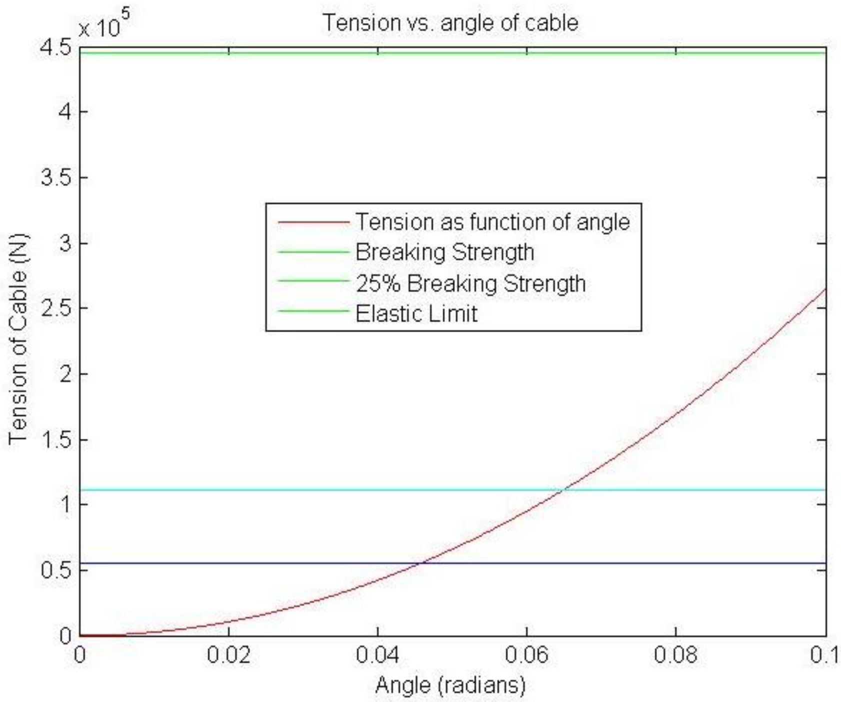
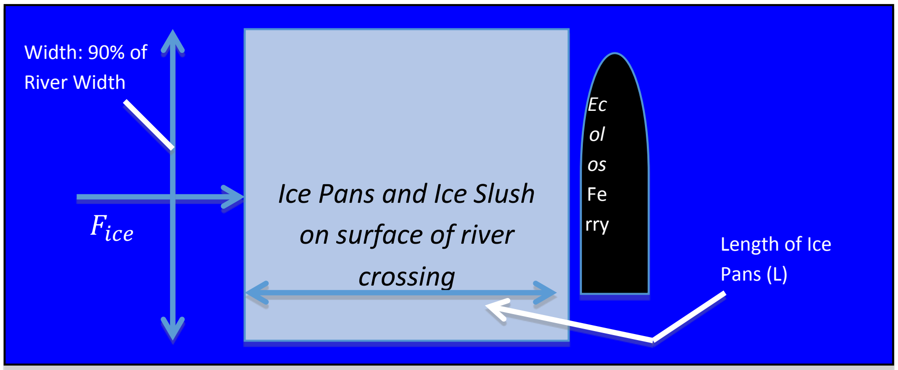


Figure 2(left) displays the relationship of the tension of the cable to the angle of the cable. The green line at the top is the normal breaking strength as reported by the ferry manufacturers. The cyan line below is the cable at 25% normal breaking strength and he blue line is the elastic limit or point at which the cable stopped acting as an elastic material. When the angle reaches around 0.045 radians it can be seen that it crosses the tension as a function of angle. This shows the point at which the cable would have snapped if the cable were at 25% breaking strength.

From the plots in figure 2 it can be concluded that if the cable was at 25% breaking strength the day of the accident than this is an accurate model of the failure. As the angle the cable makes with the wall increases, the tension in the cable increases. Once the angle made with the wall reaches approximately 0.045 radians, there is enough tension in the cable to break, which would lead to the ferry being detached from the system. The force that causes this change in angle will be analyzed more thoroughly in the next more complex model.

Complex Model

Figure 3: Diagram of force exerted on Ecolos Ferry by ice slush and pans.

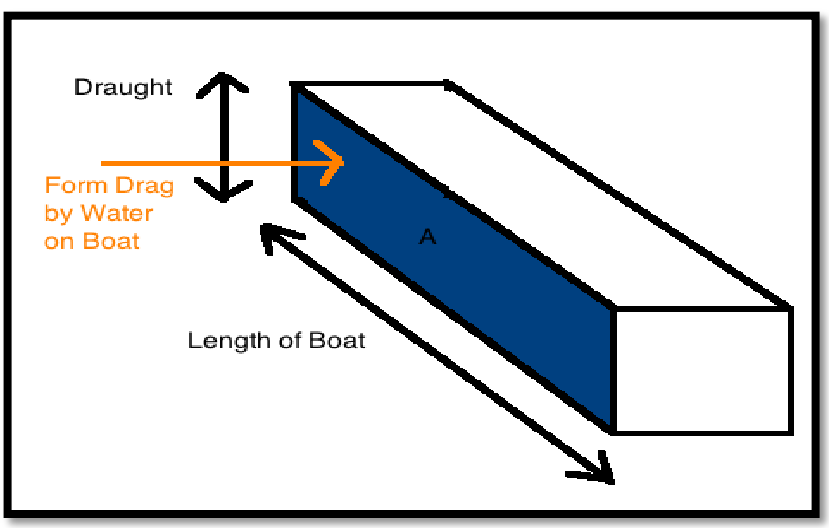


The first model represents the force of the ice on the boat as a function of the length of the ice slush and pans extending from the upstream side of the ferry. Additionally, water exerts a force on the area of the boat submerged due to form drag.

Combining these two forces, which both act in a downstream direction on the boat, yield the equation:

$$F = F_{d,boat} + F_{d,ice} \quad (6)$$

Figure 4: Diagram of force exerted on Ecolos ferry by flowing water (form drag)



Where the two terms on the right side of the equals sign correspond to the form drag force on the boat, and the surface drag force on the ice, respectively. In this model, rigid ice has accumulated on the upstream side of the ship. Water exerts a force on the ice, which is translated on to the ship, exerting a force on the cable. Note that the form drag force on the boat remains constant, as the submerged area of the boat perpendicular to the water flow does not change.

Multiple assumptions are made with this model. Firstly, it is assumed that the width of the ice is equal to 90% of the width of the river. This assumption is based on the observation that the ice sheets covered 90% of the river surface, as reported in the Preliminary Investigation Team Report on *Ecolos* Cable Failure. The force on the ice due to surface drag by water is assumed to be negligible in this model. Given that the plane of ice perpendicular to the flow of water was only millimetres in depth at the time of the failure, the drag force on the ice would not have exceeded roughly 20N. This pales in comparison to the other forces acting on the cable, which reach tens of thousands of newton's. Additionally, the mass of ice sheets and pans is assumed to be a uniform, rectangular block, all with the same surface drag coefficient of 0.01 (that of rough ice). The plane of the boat that the form drag due to water acts on is assumed to be perpendicular to the direction of the current. It therefore has a form drag coefficient of 1.28. Lastly, the density of the water is assumed to be $\frac{1000kg}{m^3}$.

The force of form drag on the boat is given by the equation:

$$F_{d,boat} = \frac{1}{2}\rho c_s A v^2 \qquad (7)$$

Where ρ is the density of the fluid (water in this case), c_s is the form drag coefficient, *A* is the exposed area of the boat, and *v* is the velocity of the water. The exposed area of the boat to water is given by the product of the length of the boat, *L*, and the draught of the boat, *D*. Therefore:

$$F_{d,boat} = \frac{1}{2}\rho c_{s,s}(L_{boat}D_{boat})v^2 \qquad (8)$$

The force of surface drag on the ice is given by the equation:

$$F_{d,ice} = \rho c_s A v^2 \qquad (9)$$

Where ρ is the density of the fluid, c_s is the surface drag coefficient (based on the nature of the surface that the force is acting on), A is the exposed area of the surface to the fluid, and v is again the speed of the fluid relative to the surface. The area in this case is given by product of the width of the ice block and the length of the ice block. Plugging this into equation (10) gives:

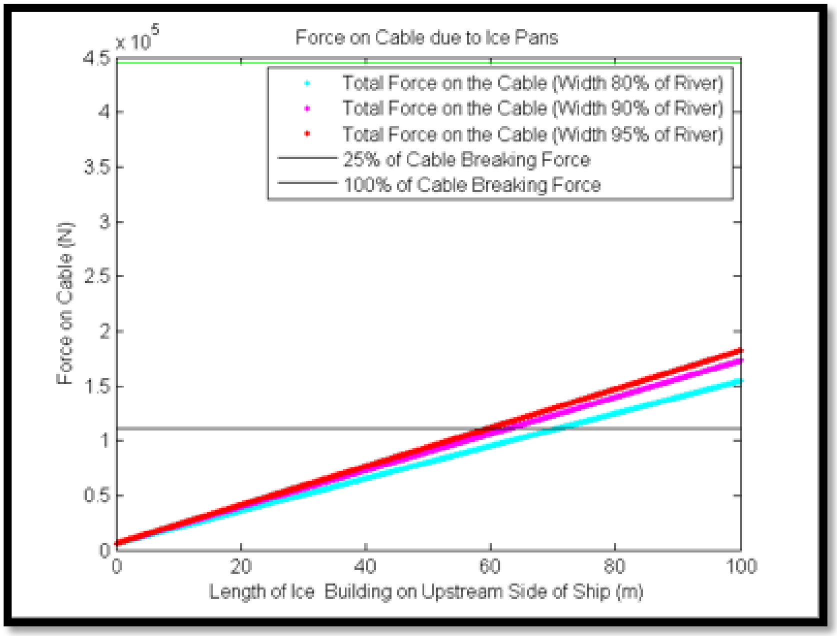
$$F_{d,ice} = \rho c_{s(f)} w_{ice} l_{ice} v^2$$

(10)

Substituting equations (10) and (8) back into the original equation for the total force (6) gives the final equation:

$$F_{TOTAL} = \frac{1}{2}\rho c_{s,s}(L_{boat}D_{boat})v^2 + \rho c_{s(f)}w_{ice}l_{ice}v^2 \qquad (11)$$

Figure 5: Length of Ice vs. Force on Side of Ship as graphed using MATLAB.



Force was plotted as a function of the length of the ice. Force values corresponding to 25% and 100% of the cable's breaking strength were included in the graph using MATLAB.

To account for the uncertainty in the width of the ice block (information from the preliminary investigation report said that ice slush and pans accounted for about 90% of the river's surface), graphs for multiple values for the width of the ice block were included.

Solving for the value of the length of the ice 'block' algebraically gives a value of 63.216m for the length of the ice block when the force on the cable meets 25% of the cable's breaking force.

This model is more complex than the simple model. It explains the forces behind the displacement of the cable, and gives a physical description of the conditions surrounding the *Ecolos* ferry at the time of the cable failure.

Individual Analysis (Student 1)

From the models created, it is possible to draw some preliminary conclusions about the case of failure. The complex model provides a good explanation of why the cable broke. It can be concluded that the force of surface drag on the ice sheet on the upstream side of the boat was the primary, if not, one of the main factors behind the failure of the cable – no other drag forces analyzed had magnitudes that were significant relative to the value of 25% of the breaking force of the cable.

However, the model is not perfect. There are many potential inaccuracies as a result of the assumptions made. For example, the width of the ice block is *assumed* to be 90% of the width of the river, and the ice block is assumed to be one large rectangular combination of ice slush and ice pans floating on the river. It's also assumed that the ice block maintains that rectangular shape as ice accumulates. This would only hold if ice or slush did *not* break off of that block and float down the river as ice accumulated, meaning there would be significant error if the ice did behave as described.

It can certainly be said that there is misleading information in the preliminary investigation report. Specifically, the information given by the public relations representative of the cable company has the capability to confuse investigators. The PR officer noted that the cable could handle up to 100,000 pounds of force, when it is evident that the cable broke at a much lower force. In the model, the ice block needed ~64m of length to accumulate enough surface drag to reach only 25% of the breaking force. Quadrupling the value of the length (the relationship between length and force is linear, with a relatively small intercept value, therefore this provides a good estimate) would yield a length value of 256 meters, which would roughly be the length of the ice block required for the force on the cable to reach 100% of the cable's breaking force. As discussed earlier, the probability of the ice block exhibiting ideal rectangular, uniform behavior up to a length of 64 meters is already unlikely, so the probability of that ice block reaching four times that value is extremely small. It is therefore very unlikely that the force on the cable reached the full value of the breaking strength of the cable, and thus the information given by the PR rep is inaccurate.

Upon graphing the data it was evident that it was far more plausible that the cable broke when the force acting on it reached 25% of the cable's breaking strength than 100%. Therefore, the intersection of the length vs. force line and the value for 25% of the breaking force was used to find the length of ice at which the cable broke.

To further improve the model, a more accurate model for the area of the ice exposed to the flowing water than simply length multiplied than width would be needed. Perhaps more accurate methods, such as using aerial photos, or conducting on-site measurements, could be conducted to provide a better estimate.

Even if the cable is replaced the risk of the cable breaking, and its associated consequences must still be accounted for. Given that the main reason for the cable failure was the accumulation of ice along the side of the ship, the risk of the cable failing increases as the amount of ice increases. Consequences in the case of the December 9th, 2010 failure were limited to damage of the property, but had the effects of the cable failure been more severe (for example, had both cables failed and the ferry been left to drift downstream without control), more severe consequences could have been incurred. Therefore, the probability of a hazard increases and its consequences become more extreme as ice amounts increase. This means that the ferry can operate under a relatively low risk in higher temperatures, but as average temperatures become lower and lower risk sharply increases. Although multiple safeguards, such as the ship being able to operate with only one cable, and lifeboats on the ship are in place, caution would need to be exercised while operating the ferry in the later months of its season. Going forward, there should be protocols set into place to prevent the ferry from operating so late into the season.

Self-Assessment

The analysis and model is clear, provided readers have an understanding of the basic physics principles behind its derivation. Readers familiar with physics laws will understand the mathematics behind the model, but it is still possible for readers with little to no physics backgrounds to understand the basics. It's not too hard to conceptualize water exhibiting a force on the ice, which in turn pushes the boat. Additionally, the fact that the model is a relatively uncomplicated linear equation helps.

With regards to fairness, the report is somewhat one-dimensional. The only perspective taken into account for the failure of the cable is the force on the cable. Factors such as water pressure on the cable, temperature, and wind conditions are not taken into consideration. Although the model of force on the cable *can* provide a reasonable explanation for the cable failure it may not explain the whole problem. In the future, these other factors should incorporate into other models to be compared with the force model.

The information used and conclusions drawn are precise, *at times*. Exact values are given for certain variables such as the draught and the length of the boat. Where there is uncertainty, such as the width of the ice block, a range of values is used in the model as opposed to a single value. Two additional force functions were plotted, with width values corresponding to 95% and 80% of the river. The range of the lengths of ice when the cable broke was then 58 to 64 meters.

Individual Analysis (Student 2)

From the models made of the Ecolos cable failure it is clear that the ferry was not intended to operate in the weather conditions present on December 9th 2010. The simple and complex models of the Ecolos ferry failure each show a different perspective as to how and why the cables failed. The first model shows that the cable failed due to the angle of the cable relative to the shore becoming too large. The second model expands on the first to analyze the forces that caused the change in angle and in turn the failure of the ferry. Together the two models allow us to conclude that the force cause by the wind, ice and water caused the cables to extend which in turn increased the tension present on the cables. Once the tension on the cable surpassed 25% of the breaking strength, the ferry failed.

This model could be inaccurate due to the fact that some of the data provided in the preliminary report was not from a fully reliable source. Most of the data stated in the report came from manufacturer specifications of the ferry and cable, this data can be counted as valid with minimal error. The data that comes from a credible source includes the ferry dimensions, cable qualities, and preliminary report tests and findings. Some of the data included in the report came from sources that are not seen as credible such as the data provided by the local meteorologist and the ferry public relations. The data obtained from these two sources include that ice thickness charts, weather, and breaking strength. Despite these sources coming from non-credible sources it can be assumed that the data is close enough to the actual values and a near accurate model can be produced.

Our second model of the ferry failure depended on the assumption that the ice accumulating against the side of the ferry was doing so in a rectangular shape. If in reality the ice was building up against the ferry in a different manner then our model would be inaccurate and adjustments would need to be made. The first model also relied on the assumption that the break occurred at exactly halfway across the river where both east and west cables were equal in length. In the report it is stated that the ferry failed approximately halfway across but, this statement was given by the operator of the ferry which not an accredited source. Once again, if this assumption is found to be erroneous then our model will be invalid and will require readjustment. The final and most influential assumption made was that the breaking strength stated by the public relations officer from the ferry company was in fact erroneous. For the purposes of the models it was decided to use the more credible findings of the preliminary report and assume that the breaking strength was not 100,000 but actually 25,000 pounds.

Considering this ferry failure occurred while there were 5 passengers on board displays just how dangerous this accident could have been. If the ferry had completely detached from the shoreline then it would have continued downstream and destroyed anything in its path. The costs alone for such a failure to occur would have been tremendous reaching well into the 100s of thousands. The ferry would have to be replaced, docks and bridges may have to be rebuild, damage to property reimbursed and lawsuits against ferry company may be placed. It`s not only the cost of this failure that should be analyzed but the safety hazards should also be identified. Having these passengers on the boat during the accident is a huge safety issue, if the ferry had completely failed major injury of even loss of life may have occurred. The fact that the ferry has no restrictions on it other than that it must operate in shallow water is completely absurd. Stricter regulations must be placed on the operation of the ferry with regards to the current of the river, speed of wind, and rate at which ice is building up. If any one of these factors is too great the ferry should not operate until the weather subsides to a more agreeable level. With the current regulations the probability of hazards is relatively high, to lower this probability additional safeguards and regulations must be implemented. Currently the only safeguards in place are the availability of lifejackets and the one-cable drive capabilities. To increase safety and reduce risk of future failures the ferry should be redesigned with an angled side that diverts the flow of ice around therefore reducing the chance of a large build-up of occurring. Another possible safe guard is the introduction of third cable that is not attached to the motor but is there to `catch` the ferry if both powered cables fail.

Self-Assessment

This section will look back onto the report and models of the ferry failure and assess the clarity, accuracy, and fairness using critical thinking methods outlined in class. Throughout our analysis and modeling of the Ecolos ferry failure we tried to make all assumptions, calculations, and logic clear to the reader no matter what their background. We included all equations used and labeled all variables so even people with minimal knowledge in the physics of stress and strain would be able to follow our conclusions. From the start of the report our objective is defined and followed through until a reasonable conclusion can be made as to what caused the ferry to fail.

The information from the preliminary report was for the most part accurate with the exception of a few values given to us by what could be known as un-credible sources. These non-credible sources include the local meteorologist, ferry PR representative and the ferry operator. These three error possibilities have been accounted for in the conclusion and although there is error in non-credible sources we assumed that they would still be a close approximation of the real value and would lead to a fairly accurate model if used. The problem with our models is that they only hold if certain assumptions made turn out to be true. These assumptions include the ice forming against the ferry in a rectangular shape and that the ferry did in fact fail when it was exactly halfway across the river; if either of these assumptions proves to be erroneous the models will fail. The information that comes from credible sources such as the preliminary tests and the manufacturers specifications have minimal error and can be trusted to be accurate by the reader.

This report accounts for many perspectives and stays unbiased from start to finish. It seems that from no matter what perspective you view this problem from it can be seen that operating the ferry in the weather conditions present on the 9th of December 2010 was a bad idea. Even the ferry operators should see the logic in this conclusion, as it is their cables and ferry that will need to be repaired before they can begin operating again.

Appendix: MATLAB Code

```
%MODEL 1: Calculating Tension as a function of angle
%Simple Model for Ecolos Cable Ferry Failure

%UNIT CONVERSIONS
intomratio = 0.0254;
lbstogratio = 453.592;
%radius of cable
radiusin = 1/2;
radiusm = radiusin * intomratio;
%Normal breaking strength of cable (N)
BS = 444822.16825;
%Breaking strength of cable at 25% (N)
BSweak = .25 * BS;
%Elastic limit of cable (N)
Elimit = BSweak/2;
%cross sectional area of cable (m^2)
A = pi*(radiusm^2);
%Elasticity modulus (N/m^2)
E = 104000000000;
%Angle the tension is changing (radians)
angle = [0:0.0001:0.1];
%Length of cable (m)
L = 512./2;
%Difference in cable length (m)
diffL = ((L./cos(angle))-L);
%Tension in cable (N)
T = E.*A.*(diffL./L);
%plot of of the tension as a function of angle, normal breaking strength,
%     25% breaking strength and elastic limit
plot(angle,T,angle,BS,angle,BSweak,angle,Elimit);
%PLOT TITLE,X-AXIS,Y-AXIS labels
title ('Tension vs. angle of cable');
legend ('Tension as function of angle','Breaking Strength',...
    '25% Breaking Strength','Elastic Limit','location','best');
xlabel ('Angle (radians)');
ylabel ('Tension of Cable (N)');
```

```
%MODEL 2: Calculating Force on Cable as a Function of Length of the Ice
%block.
%Complex Model for Ecolos Cable Failure

%Defining constants ot be used throughout model

density_kgperm3 = 1000;
form_drag_coefficient = 1.28;
length_boat_m = 18.3;
draught_boat_m = 1.39;
rel_velocity_water_mpers = 0.617;

%Calculating form drag on ship

form_drag_force_ship_N = 0.5 * density_kgperm3 * form_drag_coefficient...
    * length_boat_m * draught_boat_m * (rel_velocity_water_mpers^2);

%Calculating surface drag on ice

ice_length_m = (0:0.1:100);

surface_drag_coefficient = 0.01; %rough ice

ice_width = 487;

surface_drag_force_ice_N_90p = density_kgperm3 * surface_drag_coefficient...
    * (ice_width*0.9) * (rel_velocity_water_mpers^2) * ice_length_m;

surface_drag_force_ice_N_95p = density_kgperm3 * surface_drag_coefficient...
    * (ice_width*0.95) * (rel_velocity_water_mpers^2) * ice_length_m;

surface_drag_force_ice_N_80p = density_kgperm3 * surface_drag_coefficient...
    * (ice_width*0.80) * (rel_velocity_water_mpers^2) * ice_length_m;


%Breaking Strengths

breaking_strength_lbs_100 = 100000;
breaking_strength_lbs_25 = 25000;

breaking_strength_N_100 = 444822;
breaking_strength_N_25 = 111205.5;

% Total Force Calculation

total_force_80per = surface_drag_force_ice_N_80p + form_drag_force_ship_N;
total_force_90per = surface_drag_force_ice_N_90p + form_drag_force_ship_N;
total_force_95per = surface_drag_force_ice_N_95p + form_drag_force_ship_N;


%Plotting the data
```

```
plot(ice_length_m, total_force_80per, '.c',...
    ice_length_m, total_force_90per, '.m',...
    ice_length_m, total_force_95per, '.r',...
    ice_length_m, breaking_strength_N_25, 'k-',...
    ice_length_m, breaking_strength_N_100, 'g-');

legend('Total Force on the Cable (Width 80% of River)',...
    'Total Force on the Cable (Width 90% of River)',...
    'Total Force on the Cable (Width 95% of River)',...
    '25% of Cable Breaking Force',...
    '100% of Cable Breaking Force');
xlabel('Length of Ice  Building on Upstream Side of Ship (m)');
ylabel('Force on Cable (N)');
title('Force on Cable due to Ice Pans');
```