Analysis of Slipway Designs

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Summary

To ensure that the best facilities are built with the limited resources available in today's economy information is required on the materials of which facilities are constructed. Little research has been done on slipways and as a result the new slipways being built are not necessarily the most economical. Through testing and research of existing designs the most economical and best functioning slipway design can be determined.

By pulling a boat on existing slipways of various designs, and recording the line pulls required to pull up the boat, the frictional coefficients of the slipway materials can be determined. This information combined with the cost, safety, and the functionability of each design can determine the best slipway.

Two designs and two materials are considered. The first design being a slipway consisting of a flat sloping surface with raised runners every metre, acting as a skid surface. The second design is a flat, sloping surface with no raised runners. The two materials tested are ekki and birch. Each material is used in both of the slipway designs mentioned above.

Friction testing and economic and safety analysis reveal that the slipways with raised runners are the better alternative with the birch runners being expressed as the best choice. The rather low frictional coefficients, relatively low cost, and the safety of the design make it the best of the designs discussed.

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Introduction

In many communities in Newfoundland and Labrador, the Department of Fisheries and Oceans has constructed facilities to meet the needs of fisherman. New facilities are still being constructed and existing facilities are being repaired and improved.

Slipways in particular exist in nearly all harbours under federal jurisdiction. Several different configurations and various materials have been used in constructing slipways but little study has been done to evaluate each setup. To allow construction of the best slipway, tests should be performed on the materials used. The functionability and cost effectiveness of each material can thus be determined and the better material selected.

The materials commonly in use today are ekki, a West African hardwood (see Appendix B for detailed information) and pressure treated birch.

In addition to material, the configuration of the slipway is important. Two designs currently exist; a flat deck with raised runners spaced approximately one metre apart (figure 1), and a flat deck with no raised runners (figure 2).

Figure 1: Flat Deck Slipway

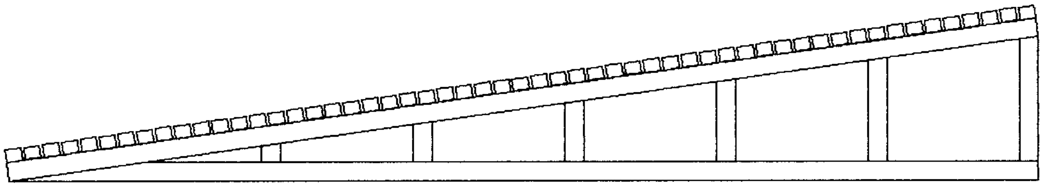
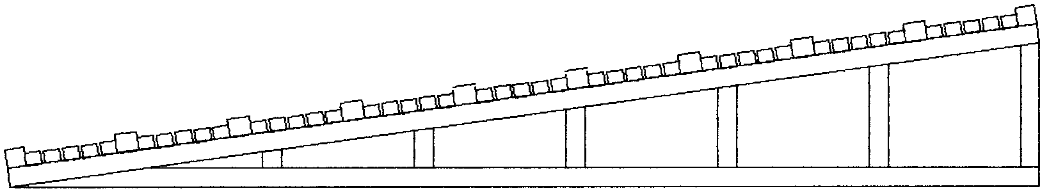


Figure 2: Slipway With Raised Runners



Through testing popular materials in each configuration the optimum setup can be determined.

Determining the Best Slipway Configuration

Testing for Friction

An important characteristic of slipway materials is their "slipperiness" or frictional coefficient. As a boat is being pulled up, a certain force is required to move it along the slipway. Two different forces are required to pull up a boat, a force to set the boat in motion, and a smaller force to keep the boat moving. These forces represent two frictional coefficients, static, to start motion, and kinetic, to keep the boat in motion. By pulling up a boat and recording the forces or line pulls required, the frictional coefficients of each of the materials with respect to the boat material can be determined. Frictional coefficients depend on both surfaces in contact, not only the slipway material but the boat material too. To give the best results for comparison the same boat was used for testing on all the slipways tested. Using the same boat eliminated problems due to the differences in individual boats.

Five locations, each representing a different configuration, were selected for testing. St. Brides was the first location tested. This community has a flat deck slipway entirely of ekki. The next location was Baine Harbour with a raised runner slipway with ekki runners. Long Cove, having a raised birch runner slipway was then tested followed by St.

Joseph's with a flat birch deck slipway. The last place tested was Prossers Rock in St. John's Harbour. This slipway has raised runners with a plastic skid surface.

The first set of tests were performed on each slipway with the skid surface and boat dry. This would simulate moving the boat around on the slipway after it has been pulled up.

The testing involved placing the boat on the slipway and, by using a winch, pulling the boat along the skid surface of the slipway. Two readings of line pull were recorded; the pull required to set the boat in motion and the pull required to keep the boat moving. The pull required to set the boat in motion representing the force to overcome static friction; the pull required to keep the boat in motion representing the force to overcome kinetic friction.

The second set of tests were performed with the boat and slipway wet. Wetting the slipway surface would reduce the friction and wetting the boat would represent the typical hauling of a boat out of water.

The testing involved placing the boat in the water and then throwing buckets of water onto the skid surface of the slipway. The boat was pulled along the skid surface and, as in the first tests, two readings were taken.

With the friction testing complete, using a surveying level, rod and a measuring tape, information was gathered so that the slope of the slipway could be determined.

After all testing had been performed, the boat was weighed. Then using the data obtained, a comparison of the slipways began.

Analysis

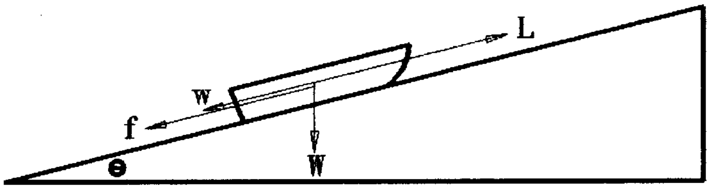
Several trials of each test were performed. An average line pull for static and kinetic friction was determined (See Appendix A). Using the average line pulls, the weight of the boat, and the measured slope of the slipways, the coefficients of static and kinetic friction can be determined using the following relationship:

Static:

$$L_s = w + f_s$$

$$L_s = W \sin(\theta) + \mu_s W \cos(\theta)$$

$$\mu_s = \frac{L_s - W \sin(\theta)}{W \cos(\theta)}$$



Kinetic:

$$L_k = w + f_k$$

$$L_k = W \sin(\theta) + \mu_k W \cos(\theta)$$

$$\mu_k = \frac{L_k - W \sin(\theta)}{W \cos(\theta)}$$

where: L_s = static line pull
L_k = kinetic line pull
W = weight of boat
w = component of weight in plane of slipway
f_s = static frictional force
f_k = kinetic frictional force
θ = angular slope of slipway

The frictional coefficients for each slipway were determined (see Appendix A) and are as follows:

Table 1: Frictional Coefficients

Community	Dry Slipway		Wet Slipway	
	Static	Kinetic	Static	Kinetic
St. Brides (Flat Ekki Deck)	.74	.41	.06	.31
Baine Harbour (Ekki Runners)	.87	.32	.65	.25
Long Cove (Birch Runners)	.36	.22	.21	.18
St.Joseph's (Flat Birch Deck)	.46	.30	.29	.11
Prossers Rock (Plastic Runners)	.04	.02	.04	.02

Cost

The frictional coefficients are not the only important factor in slipway construction. Cost is also very important.

The two materials currently in use are ekki and pressure treated birch. Their respective costs are $2400 and $1200 per one thousand board feet. A board foot is a piece of wood one foot by one foot by one inch thick. Because of varying sizes in the slipways tested a 20 square foot model will be used to calculate cost.

The flat ekki deck slipway of the type in St. Brides uses two by ten inch ekki plank. Assuming a surface area of twenty square feet, twenty four feet of ekki plank would be required, that is, twenty four feet of ten inch wide ekki plank would be required to cover a twenty square foot surface. The number of board feet can be determined using the relationship:

$$\frac{\text{width} * \text{thickness} * \text{length}}{12} = n \text{ fbm}$$

where width and thickness are in inches and length in feet.

The amount of ekki required, using the above relationship is 40 fbm. At $2.40 per fbm, enough ekki to cover twenty square feet, would cost $96.00.

A flat birch deck of the type in St. Joseph's uses four by five inch birch plank. To cover twenty square feet, forty-eight feet of birch plank would be required. Forty-eight feet of four by five inch treated birch is 80 fbm. At a cost of

$1.20 per fbm, enough birch to cover twenty square feet would cost $96.00.

Slipways with raised runners use four by six inch runners spaced approximately three feet apart with three by four inch spruce boards between runners. For twenty square feet, seven feet of runner and forty-two feet of spruce board would be required. Fifty two board feet of spruce board would be required at $800 per 1000 fbm costing $42.00. Fourteen board feet of runner would be required costing $17.00 for birch and $34.00 for ekki. The total initial cost for twenty square feet would be: for ekki runners, $76.00, and for birch runners, $59.00.

The service life of each slipway should also be taken into account and the total economic life of each slipway considered. Ekki has an estimated service life of forty to fifty years and treated birch twenty to twenty-five years.

Assuming a forty year period, a flat deck ekki slipway, with an initial cost of approximately $100 per twenty square feet would not require replacement. A flat birch deck at approximately the same cost would require replacement once in forty years.

A raised runner slipway of ekki would cost approximately $75 and, assuming no wear to the spruce boards between runners, would not require replacement in a forty year period. A slipway with raised birch runners with an initial cost of

$60.00 would require replacement once.

The last type of slipway had raised ekki runners with a plastic skid surface. The plastic strips are an additional $10 per foot or $70 for twenty square feet giving a total cost of approximately $150.

In terms of present value, the raised runner slipways, with the exception of the plastic covered ekki, are cheaper. Depending on inflation and interest rates, both the birch and ekki slipways would have a similar present value.

The flat deck slipways are more expensive than raised runner slipways with the flat birch slipway being more expensive than the ekki. The most expensive configuration is the raised ekki runners with the plastic skid plate.

Safety

A slipway surface should be safe to walk on yet allow easy pulling of a boat. On flat deck slipways boats are pull on the entire surface of the slipway. However, on slipways with runners, only the runners have contact with the boat. The frictional coefficient of the surface between the runners is not important. A good walking surface can be placed between runners without concern of its affects on a boat. On a flat deck slipway a relatively slippery surface must be maintained on its entire length. Clearly then, a slipway with raised runners is safer for walking.

Ease of Use

Ease of use of a slipway would be indicated by an absence of problems when pulling up or launching a boat. Generally, boats are pulled up bow first and launched stern first. On flat deck slipways few problems occur with this method of launching. However on slipways with raised runners, the keel of the boat tends to catch on the runners as it slides back. The keel of the boat then has to be lifted clear of the runners as the boat slides towards the water. To prevent the boat catching on the runners it can be turned around so that it slides bow first into the water. However, turning a boat on a crowded slipway can be very difficult. In addition, in the case of Prossers Rock, the slipway with plastic runners, the skid surface had very little friction, so little in fact that the boat when nudged slightly would slide, on its own, out into the water. This characteristic could cause many problems. It would be very easy to lose control of a boat while moving or launching it on such a surface.

In terms of ease of use the flat deck slipways performed better.

Conclusions and Recommendations

To determine the optimal choice for slipway design four factors can be considered, frictional coefficients, life cost, safety, and ease of use. Creating a weighted decision matrix using these factors helps make the best alternative more obvious.

Table 2: Decision Matrix

Community	Friction x 1	Life Cost x 3.0	Safety x 10	Ease of Use x 2	Total
St.Brides	1.9	1.0	0.5	1.0	11.9
Baine Harbour	1.9	1.5	1.0	0.5	17.4
Long Cove	4.2	1.5	1.0	0.5	19.7
St.Joseph's	3.4	1.0	0.5	1.0	13.4
Prossers Rock	0	.75	0.1	0.1	3.45

The numbers used above were determined in the following ways. With the exception of Prossers Rock, the numbers for friction are the inverse of the average of the four coefficients determined in Appendix A. Prossers Rock slipway is for practical purposes too slippery. Used only as a haul out facility it is adequate, but for storage it is unsuitable. Because of its excessive slipperiness Prossers Rock was given a zero.

The number for life cost was determined based on the approximate present value of the total cost of the slipway in a forty year span. The present value of a twenty square foot slipway was converted into a percentage of one hundred dollars. This percentage was then inverted to give the number used.

The number for safety was determined using one for slipways with runners and one-half for flat deck slipways. The number for ease of use was determined similarly using one for flat deck slipways and one half for slipways with runners.

The total represents the sum of numbers in each row multiplied by their weight factors (1 for friction, 3 for cost, 10 for safety, and 2 for ease of use). The slipway with the highest total would be the best alternative.

It can be seen from the decision matrix that the slipways with raised runners are the better alternative with the birch runners being expressed as the best choice. The rather low frictional coefficients, relatively low cost, and the safety of the design make it the perferred alternative in comparison to the others studied.

It should be noted though, that due to time constraints, only one slipway of each type was tested. For the results to be conclusive several slipways of each type should have been tested. Differences in individual slipways could then be considered.

Appendix A:

Determination of the Frictional Coefficients of Selected Slipways

Using the average line pulls, the weight of the boat, and the measured slope of the slipways, the coefficients of static and kinetic friction can be determined using the following relationship:

Static:

$L_s = w + f_s$

$L_s = W \sin(\theta) + \mu_s W \cos(\theta)$

$$\mu_s = \frac{L_s - W \sin(\theta)}{W \cos(\theta)}$$

Kinetic:

$L_k = w + f_k$

$L_k = W \sin(\theta) + \mu_k W \cos(\theta)$

$$\mu_k = \frac{L_k - W \sin(\theta)}{W \cos(\theta)}$$

where: L_s = static line pull

L_k = kinetic line pull

w = component of weight in plane of slipway

f_s = static frictional force

f_k = kinetic frictional force

θ = angular slope of slipway

W = weight of boat

As testing on each slipway progressed, the line pulls needed to pull the boats were recorded. These line pulls are displayed in the table below.

Table 3: Line Pull Required to Pull Boat on Slipways When Dry

Community	St. Brides Flat Ekki		Baine Harbour Ekki Runners		Long Cove Birch Runners		St. Joseph's Flat Birch		Prossers Rock Plastic Runners	
Line Pull	Static	Kinetic	Static	Kinetic	Static	Kinetic	Static	Kinetic	Static	Kinetic
	500	300	600	300	300	210	390	310	110	100
	500	280	610	250	300	210	390	310	110	100
	510	270	570	250	300	210	390	310	110	100
	500	270	600	250	300	210	410	310	110	100
	510	300	600	250	310	210	450	330	110	100
	500	280	600	280	300	220	410	310	110	100
	500	330	600	250	300	210	410	310		
	500	330	610	280	290	200	410	310		
Average	503	295	599	264	300	210	408	313	110	100

Table 4: Line Pull Required to Pull Boat on Slipways When Wet

Community	St. Brides Flat Ekki		Baine Harbour Ekki Runners		Long Cove Birch Runners		St. Joseph's Flat Birch		Prossers Rock Plastic Runners	
Line Pull	Static	Kinetic	Static	Kinetic	Static	Kinetic	Static	Kinetic	Static	Kinetic
	400	250	450	250	210	190	310	190	110	100
	400	230	450	200	210	190	310	190	110	100
	400	220	500	200	210	190	310	190	110	100
	450	220	430	200	210	180	310	210	110	100
	400	250	450	200	200	190	300	210	110	100
	400	230	470	230	210	190	300	200	110	100
	400	250	510	200	210	180	310	190		
	450	250	450	250	200	190	320	190		
Average	413	238	464	216	208	188	309	196	110	100

The slopes of the slipways were obtained by taking an upper and lower reading with a surveying level and measuring the distance between each reading location. The angle of slope can be determined as follows.

The slopes of the slipways tested are displayed in the table below.

Table 5: Slopes of the Tested Slipways

Community	Level Readings(mm)		Distance(mm)	Angle (deg)
	Upper	Lower		
St.Brides	2173	1118	15011	4.0
Baine Harbour	2244	184	20065	5.9
Long Cove	2018	782	9940	7.1
St.Joseph's	2310	1132	5590	12.2
Prossers Rock	2210	1036	8483	8.0

After all testing was complete the boat was weighed and found to be six hundred and twenty pounds. The line pulls, slope of each slipway, and the weight of the boat have been determined. The frictional coefficients can now be determined using the relationship previously expressed.

Table 6: Determination of Coefficient of Static Friction - Dry Slipway

Community	Line Pull (lbs)	Weight of Boat (lbs)	Slope of Slipway (deg)	Frictional Coefficient
St.Brides	503	620	4.0	0.74
Baine Harbour	599	620	5.9	0.87
Long Cove	300	620	7.1	0.36
St.Joseph's	408	620	12.2	0.46
Prossers rock	110	620	8.0	0.04

Table 7: Determination of Coefficient of Kinetic Friction - Dry Slipway

Community	Line Pull (lbs)	Weight of Boat (lbs)	Slope of Slipway (deg)	Frictional Coefficient
St.Brides	295	620	4.0	0.41
Baine Harbour	264	620	5.9	0.32
Long Cove	210	620	7.1	0.22
St.Joseph's	313	620	12.2	0.30
Prossers rock	100	620	8.0	0.02

Table 8: Determination of Coefficient of Static Friction - Wet Slipway

Community	Line Pull (lbs)	Weight of Boat (lbs)	Slope of Slipway (deg)	Frictional Coefficient
St.Brides	413	620	4.0	0.60
Baine Harbour	464	620	5.9	0.65
Long Cove	208	620	7.1	0.21
St.Joseph's	309	620	12.2	0.29
Prossers Rock	110	620	8.0	0.04

Table 9: Determination of Coefficient of Kinetic Friction - Wet Slipway

Community	Line Pull (lbs)	Weight of Boat (lbs)	Slope of Slipway (deg)	Frictional Coefficient
St.Brides	238	620	4.0	0.31
Baine Harbour	216	620	5.9	0.25
Long Cove	188	620	7.1	0.18
St.Joseph's	196	620	12.2	0.11
Prossers Rock	100	620	8.0	0.02

Appendix B:

Information on Ekki

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INFORMATION SHEET

EKKI (AZOBE or BONGOSSI)

Botanical name Lophira alata va. procera

AN EXTREMELY HARD, HEAVY AND DURABLE TIMBER FROM WEST AFRICA

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EKKI is one of the most NATURALLY durable timbers. No preservatives of any kind are required. EKKI is environmentally benign.

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EKKI is more resistant to fire and flamespread than even heavily fire retardant treated softwoods.

EKKI has an extremely high crushing strength.

Typical applications of EKKI are:

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- Decking for piers, bridges, platforms and walkways
- Bridge structural members
- Timbers for weirs and stoplocks
- Lock gates
- Timbers for sewage treatment installations
- Rubbing strips and timbers
- Finger docks
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THE DURABILITY OF SOME WOOD SPECIES

Wood species are categorized in five classes according to their NATURAL (untreated) resistance to biological attack and degradation in temperate climates. The numbers of years indicates the duration that these woods may be in direct contact with bacteria laden soils without ill effect.

CLASS	NO. YEARS	SPECIES
I	more than 25	Teak, Jarrah, Greenheart, Yellow Cedar, some Eucalyptus, EKKI (AZOBE), Basralocus, Mambarklak, Wallaba
II	15-25	Western Red Cedar, California Redwood, White Oak
III	10-15	Most pine species, Douglas Fir, Some Hemlocks
IV	10-5	Some Firs, Some Hemlocks, Red Oak.
V	less than 5	Alder, Poplar, Linden, Birch

Source: Institute for Wood Research in Delft, Holland and the Wood Reference Institute of Amsterdam.

	EKKI	Douglas Fir		Southern Pine		Western Hemlock		White Oak	
Bending	250	120	140	120	140	100	120	120	140
Tension ∥ to grain	220	110	120	110	120	90	100	110	120
Compr. ∥ to grain	220	80	110	80	110	70	95	85	110
Compr. ⊥ to grain	80	18	30	18	30	14	22	35	45
Shear	20	10	10	12	14	10	10	16	18
Mod. of Elasticity in Bending (X1000)	170	110	130	110	130	100	110	80	95

Units are Kg/cm^2

SAFE WORKING STRESSES FOR A NUMBER OF WOOD SPECIES

Source: "Working Stresses for a Number of Wood Species" by Prof. A. Grover, published by the Houtinstitute TNO, Delft, The Netherlands.

Notes: 1. The values in the column under EKKI is for green timber. EKKI is typically used only in the green state. It dries very slowly. With drying, the values of the safe working stresses increase.

2. The values in the first column is for green timber. The values in the second column is for kiln dried timber with a moisture content not exceeding 15%.

Average values, unseasoned timber (inch-pound units)

Clear samples

	Note 1 EKKI	Douglas Fir	Eastern Cedar	Jack Pine	Spruce	White Oak	Western Hemlock
Static Bending:							
Stress at Prop. Limit	13,850	4,320	2,020	3,450	3,090	3,730	4,110
Mod. of Rupture	22,870	7,540	3,860	6,310	5,870	8,710	6,960
Mod. of Elas. (x 1000)	2,732	1,610	515	1,170	1,320	1,510	1,480
Work in bending:							
To Prop. Limit	3.56	.66	.46	.60	.42	.52	.66
To Max Load	33.50	7.10	8.50	7.10	8.40	18.60	6.70
Compr. // to grain:							
Stress at Prop. Limit	8,470	2,810	1,230	2,010	1,840	2,130	2,980
Max. Crushing Strength	10,450	3,610	1,890	2,950	2,760	3,580	3,580
Mod. of Elas. (x 1000)	2,734	1,670	546	1,190	1,470	1,680	1,620
Comp.⊥ to grain:							
Stress at Prop. Limit	2,420	460	196	335	300	716	373
Shear // to grain:							
Avg. Max. Stress	2,493	922	660	822	796	1,264	752
Cleavage (lb/inch width)	605	216	160	188	180	488	202
Tension grain:							
Max. Stress	1,555	407	328	354	340	869	390
Hardness: see note 2							
Side	3,810	480	270	394	378	1,260	468
End	4,310	589	364	412	414	1,270	561

Sources: Imperial Institute London for the values of EKKI.
Strength and Related Properties of Woods Grown in Canada, by Forintek Ottawa, Published by Supply and Services Canada, Catalogue No. FO64-21/1977.

Note 1: EKKI samples dried to estimated value of about 17.3% MC.
Note 2: Force in pounds to imbed .444 inch steel ball to half diameter.

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