Wear and Friction Modelling on Lifeboat Launch Systems

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ABSTRACT

The RNLI provides search and rescue cover along the UK and RoI coast using a variety of lifeboats

and launch techniques. In locations where there is no natural harbour it is necessary to use a slipway

to launch the lifeboat into the sea. Lifeboat slipway stations consist of an initial section where the

boat is held on rollers followed by an inclined keelway lined with low friction composite materials,

the lifeboat is released from the top of the slipway and proceeds under its own weight into the water.

The lifeboat is later recovered using a winch line. It is common to manually apply grease to the

composite slipway lining before each launch and recovery in order to ensure sufficiently low friction

for successful operation. With the introduction of the Tamar class lifeboat it is necessary to upgrade

existing boathouses and standardise slipway operational procedures to ensure consistent operation.

The higher contact pressures associated with the new lifeboat have led to issues of high friction and

wear on the composite slipway linings and the manual application of grease to reduce friction is to be

restricted due to environmental impact and cost factors. This paper presents a multidisciplinary

approach to modelling slipway panel wear and friction using tribometer testing in conjunction with

finite element analysis and slipway condition surveys to incorporate common real-world effects such

as panel misalignments. Finally, it is shown that a freshwater lubrication system is effective,

reducing cost and environmental impacts while maintaining good friction and wear performance.

KEYWORDS:

Lifeboats, marine, friction mechanisms, stress analysis, wear mechanisms

OVERVIEW OF SLIPWAY LAUNCHED LIFEBOAT OPERATION

The RNLI provides search and rescue (SAR) cover around the coast of the UK and Ireland. In areas

where there is no natural harbour, and the ground is not suitable for carriage launched lifeboats the

only option allowing a lifeboat to launch in all weather conditions is to use an inclined slipway. The

RNLI operates 18 slipway stations in the UK and 2 in the Republic of Ireland, each station is

different and each has its own historical launch techniques and slipway geometries though they all

follow a common template [1]. The most common configuration is to have an upper section of steel

rollers leading onto a smooth, lined, lower section with a typical gradient of 1 in 5. The boat is

launched down the slipway resting on its keel with the plane slipway section coated with grease to

reduce friction. The boat is recovered by manoeuvring the keel onto the bottom of the keelway

before attaching a winch cable and hauling the boat to the top of the slipway. With the advent of

modern, heavier slip launched SAR (search and rescue) craft such as the 35+ tonne Tamar class

(being phased in across the country from 2005) [2, 3] significant modifications to, or replacement of

existing boathouses and slipways are required due to its larger size and mass with a graphite infused

jute fibre/phenolic resin composite material originally developed as a dry or water lubricated marine

bearing as the preferred lining for all new and reconditioned slipways.

The composite has been chosen in part for its proposed ability to achieve suitably low friction

coefficients without the use of grease, which is currently manually applied to the slipway lining

before each launch and recovery.

Real-world slipway use has highlighted a number of issues with high friction and wear of composite

slipway panels, particularly at the newly reconditioned slipways currently using the new Tamar

lifeboat. Slipway performance is regularly assessed by the RNLI during slipway trials, here the boat

is recovered to the top of the slipway using a winch fitted with a load cell, the recorded load is used

to calculate the dynamic and static friction coefficients during a series of hauls. Friction performance

has been observed to be unpredictable, this manifests as high winch loading as the lifeboat is

recovered to the top of the slipway. This has implications for the winch lifespan and for the wider

reliable operation of slipway launched lifeboats. Wear performance is also observed to be poor with

composite panels noted to be eroding very quickly, often requiring replacement within months or

even weeks compared to the expected panel design life of 2 years. This has implications for reliable

lifeboat operation and for the maintenance costs of slipways, the composite panels are expensive and

current replacement rates are shown to be financially unsustainable.

This work is intended towards a method for evaluating the friction and wear performance of the

graphite infused jute fibre/phenolic resin composite slipway lining and to identify and reduce the

causes of high friction and high wear on the slipway panels. Suitable lubricants to ensure low friction

coefficients and hence reliable slipway operation are also investigated.

FIG 1

PREVIOUS WORK

Previous work in this area has involved using tribometer testing to evaluate the friction [4] and wear

[5] performance of slipway panels. This revealed that the dry sliding friction coefficient of the

composite slipway panels under normal in-service loading was not sufficient to ensure reliable

slipway performance; hence, a lubricant is required.

Lubricants tested included the currently used marine grease, two biodegradeable greases suggested

for direct substitution with the marine grease, a cable pulling lubricant used at Sennen Cove slipway

station and freshwater and seawater lubrication systems. All lubricants bar one of the biogreases

were found to be suitable for reducing friction along the slipway to within design limits. This led to

the recommendation to adopt a water lubrication system due to its low initial and operating costs,

low environmental impact and good friction performance.

Wear rates [5] were found to be uniformly low for all lubricants tested, far lower than those found on

real world slipways and insufficient to explain the high failure rates and subsequent replacement

costs of slipway panels. This has prompted a detailed investigation and condition survey of existing

slipways for indications as to the causes of the high wear observed.

SLIPWAY CONDITION SURVEYS

Following the low wear rates noted during the tribometer testing detailed photographic surveys of

real-world slipway panel conditions were conducted at a number of slipway stations operating both

the new Tamar class lifeboat and the older Tyne class lifeboat to investigate why real-world wear

rates are found to be so much higher than those indicated by the tribometer tests.

Photographic slipway surveys were conducted at Bembridge, Sennen cove, The Lizard, Selsey,

Tenby and Padstow; with additional panel alignment surveys conducted on the new Tamar operating

Tenby and Padstow slipways.

Real World Slipway Panel Wear

Wear on the composite slipway panels is observed from slipway surveys to fall into four main

categories, termed panel end wear, gouging wear, plane abrasive wear and delamination wear.

Panel End Wear

This type of wear is reported by lifeboat crews as the main cause of panel failure. It is defined as

wear that takes place at the ends of each panel and appears to be more pronounced on the raised edge

of panels that are misaligned in relation to their neighbours. The actual wear can take different

forms, from simple abrasion to more complex cracking effects as detailed below.

Panel End Abrasive Wear

This is the most common form of panel end wear observed from the slipway surveys; it represents

the case where abrasive wear has resulted in a relatively even and graded wear scar, as opposed to

the larger scale panel cracking effects observed elsewhere.

FIG 2

Fig. 2 above shows the typical progression of an abrasive wear scar on a misaligned panel. Initially

panel end stresses cause a small region of the composite to deteriorate and fail, this initial

imperfection develops until it is the width of the lifeboat keel on the panel. Further slipway operation

causes this wear scar to progress into the composite panel until it reaches the level of the fixing bolts,

at this point the panel is considered to have failed as it is no longer sufficiently attached to the

slipway superstructure.

Panel End Cracking Wear

Panel end stresses can also result in the formation of deep cracks in the phenolic resin of the

composite, these can progress to form panel 'islands' where the phenolic resin has cracked but the

jute fibre mesh retains the cracked section in place. The jute fibres eventually fail leaving the

cracked material to break loose of the main panel, this results in distinctive large scale missing

'chunks' on the panel ends. This effect is noted to be more pronounced on misaligned panels and is

suspected to be caused by the same stress concentration effects. Fig. 3 shows the progression of this

process on different panels.

A subset of the cracking to leave panel 'islands' case is where cantilever effects (where the panel is

not adequately supported after the final fixing bolts) can result in cracking of the phenolic bulk

materials between the fixing bolts as show below in fig. 4. This type of wear is severe as once the

cracked section separates from the main panel the holes for the fixing bolts are broken also and the

panel can be considered to have failed as it is not adequately fixed to the underlying slipway

structure.

FIG 3

FIG 4

Gouging Wear

Deep, parallel gouging wear scars are observed at the new Tamar equipped Padstow and Tenby

slipways. These are subsequently attributed to an imperfection in the keel of the prototype Tamar

class lifeboat, used for initial slipway hauling trials at both slipways.

FIG 5

This issue has since been rectified and the absence of other significant gouging wear scars on the

Tamar slipways and general slipway friction performance better than that expected from ploughing

friction calculations indicate that once the prototype Tamar keel was repaired no other major

gouging wear was encountered here. This is supported by the other slipway inspections at Selsey and

Bembridge where some light gouging wear is present, though not to the severity that would be

expected for the large number of launches and recoveries conducted on these slipways. This supports

the proposition that significant, persistent keel damage not a common occurrence on slipways and

raises the possibility that the lighter gouging wear scars on Selsey and Bembridge slipways are

caused by 3rd party wear particles trapped between the contact. This is supported by the presence of

diagonal and wavy gouging scars on panels, if the scars were caused solely by keel imperfections

these would be expected to run along the length of the slipway lining as the lifeboat does not move

laterally as it proceeds along the slipway, this is shown in fig. 6 below:

FIG 6

Overall the impact of gouging wear on the slipway is unlikely to have a significant systemic effect

on slipway function, the presence of straight gouging grooves on the slipway panels is an early

indicator of keel damage and this should be identified and remedied before further slipway lining

damage occurs. However, the low number of gouging wear scars on other composite slipways

indicates that this is likely to be an infrequent problem. The presence of wavy or diagonal wear scars

on the slipway indicates the presence of 3rd body particles between the keel and slipway lining, as

these are not attached to either contact face they are likely to be removed from the slipway by the

process of lifeboat launch and recovery. Similarly the low incidence of this type of gouging wear on

the slipways surveyed indicates that this is likely to be an infrequent problem, however if these wear

scars are noted to appear regularly on a specific slipway it may be necessary to inspect the slipway

for debris before use. Interestingly, the diagonal wear scars indicating 3rd body wear are also present

on the water lubricated Tamar slipways at Padstow and Tenby, it had been thought that a by-product

of the use of running water along the slipway would be to remove any potential wear debris from the slipway lining surface but this does not appear to be the case.

Plane Abrasive Wear

Plane abrasive wear occurs when the slipway panel is well aligned and the contact with the keel is even and planar, in this case the contact pressures are relatively evenly distributed along the panel and the resulting wear is light and even. This typically results in the phenolic bulk of the composite material eroding to expose the underlying jute fibres.

FIG 7

The incidence of plane abrasive wear on a panel is a sign that the panel is performing well and that the keel contact is well aligned. Under these contact conditions wear will be very light, approaching the wear rates observed during the aligned contact tribometer testing.

Delamination wear

A further wear mechanism noted is the incidence of delamination, here the upper layer of the composite has separated and worn away leaving an uneven bearing surface.

This kind of wear is noted at both of the new Tamar equipped slipways at Tenby and Padstow. The progression of delamination wear is shown in fig. 8. Here the wear is shown to develop initially as small pits the depth of a composite layer, before the pits widen and join to form large areas of delamination along the slipway.

FIG 8

Close up images of delamination wear on the composite slipway lining material are shown in fig. 9.

FIG 9

Delamination of the composite slipway panels implies that there are high shear stresses present in the composite bulk around the contact area, and this in turn implies that friction forces and friction coefficients are high in these regions. This leads to the conclusion that the presence of delamination on slipway panels indicates well aligned contact conditions, but high frictional forces on the panel. The presence of delamination wear on the new Tamar equipped slipways may be due to a breakdown of the lubrication regime to allow unlubricated contact or a consequence of running the slipway dry.

Impact Wear

Near the base of the slipway some lining panels were observed to have been damaged by the impact of the keel as the lifeboat mounts the slipway. The recovery technique involves the coxswain trying to 'surf' onto the base of the slipway on a wave, the water subsequently receding to leave the lifeboat sufficiently 'stuck' on the slipway to attach the winch cable. This naturally involves the keel impacting the slipway lining with some force and this can occasionally damage the slipway panels.

Embedded Debris

Embedded debris is noted at Selsey slipway, conversations with the coxswain indicate that this is likely to be animal shells, this is confirmed by observation of snails and snail trails on slipway panels.

FIG 10

PANEL MISALIGNMENT SURVEYS

Photographic surveys of a number of real world slipways were conducted in order to develop a picture of the typical wear patterns developed by the slipway panels. During these investigations it was observed that there was sometimes severe misalignment between slipway panels along the slipway. It was noted that the most severely worn panels seemed to coincide with the more pronounced panel misalignments and this led to more comprehensive slipway panel surveys at the new slipway stations of Tenby and Padstow to ascertain the extent of this misalignment.

Tenby Slipway Panel Alignment Survey

Measurements of the height difference between slipway panels were taken at each corner of each panel and recorded for the extent of both slipways above the waterline. These show that the panel misalignment is present and significant, reaching a peak of 3.52mm height difference between panel 18 and 19 (panels are numbered from the top of the slipway towards the waterline). Wear on panel 19 (raised in relation to panel 18) is observed to be primarily end wear with cracking well developed on the panel despite it having been only recently replaced. Overall the slipway shows an average height difference between panels of 0.88mm with a maximum of 3.52mm.

Padstow Slipway Panel Alignment Survey

At Padstow it is also observed that the composite panels with the most pronounced end wear are often vertically misaligned with respect to their neighbouring panels producing a raised edge which is likely to generate stress and wear concentrations. A detailed panel misalignment survey is conducted in a similar way as at Tenby slipway and it is found that panel misalignment is present and significant along the slipway with an average panel height difference of 0.73mm and a maximum of 4.06mm.

Panel Alignment Observations

The panel misalignment surveys conducted at Tenby and Padstow indicate that significant panel misalignment is present along the slipway in both cases.

The average offset for all panels recorded from both slipway surveys is 0.82mm. The compressive yield strain is recorded as 1.9% for the composite, on a 19mm thick panel this would correspond to a displacement of 0.36mm, less than half of the average panel height difference along the slipway. This indicates that compressive deformation of the composite panels is not sufficient to accommodate the panel misalignments present at both Tenby and Padstow slipways, even at the maximum compressive deformation before failure. As the contact stresses around the raised edge of a misaligned slipway panel are likely to be high this will contribute to increased wear in the area and this is reflected by observation. The high contact forces will also have an adverse effect on friction according to the theory.

FEA MODELLING OF EXISTING SLIPWAY PANEL GEOMETRY

Following tribometer testing the friction and wear rates for the composite against steel under various lubrication regimes are determined. However, the wear scars generated bear little resemblance to the real world case and the friction is also observed to be far more stable. From investigation of the worn Tenby slipway panel it is noted that wear occurs, not evenly across the keel/panel contact area as expected from an evenly distributed load on a flat surface, and as generated by the tribometer tests, but unevenly, and particularly at the panel edge and area surrounding the fixing holes. This would imply that the evenly distributed load/flat surface assumption does not hold entirely for the length of the lifeboat keel in the real world case. Site surveys undertaken at Tenby and Padstow to determine the extents and nature of the uneven wear observed found that there was significant misalignment present between panels, the nature of which could be roughly categorised into three misalignment scenarios. It is thought that this deviation from the evenly distributed load/flat surface contact may be a cause of the higher than expected friction and wear observed on real world lifeboat slipways. In order to assess the impact of the panel geometry and alignment on the wear rate it is proposed to use finite element methods in ANSYS coupled with the friction and wear data derived experimentally from tribometer testing.

FIG 11

One Panel Aligned Case

Finite Element techniques are used to model the static case of an evenly distributed load along the lifeboat keel on a composite slipway panel; results are shown below for the Von Mises stresses on the panel.

It is found that the areas of high stress concentrations correlate well with the worn regions observed

on composite panels during slipway surveys and on the damaged slipway panel recovered from Tenby

slipway station as shown in fig 12.

The stress concentrations on the FEA model are seen to occur around areas close to geometric

features, particularly the panel edge and fixing hole areas. This would indicate that geometric

considerations are an important factor in determining the likely local wear rate and friction on a

slipway panel due to the stresses concentrated in these areas.

FIG 12

Wear Simulation

Using element death techniques and appropriate element failure criteria a wear scar can be developed

within the FEA model. This is done by using a fine element mesh around the expected wear

concentrations, elements exhibiting stresses above the material failure criteria are 'killed' and

removed from the analysis, generating a wear scar. Using iterative techniques this wear scar can be

modelled over time to show the likely progression of wear on the slipway panel. The wear scar

generated is shown to correlate well with the real world case as shown below.

FIG 13

Using this technique the wear progression on the composite slipway panel can be modelled beyond

the current subjective visual replacement criteria as shown below. This data indicates that the initial

edge wear will develop over time into more serious progressive wear, a feature also observed during

slipway surveys where panels exhibiting different stages of edge wear indicated the same

progression. The wear modelling below also shows the development of delamination, predicting that

this type of wear will be more pronounced around geometric features such as panel fixing holes, this

again confirms observations from real world slipway panel surveys.

Another aspect of this simulation of wear progression is that the panel bearing area is progressively

reduced as the composite material is abraded with a consequential increase in the apparent contact

pressure as the lifeboat mass load is distributed over a reduced area. This will lead to an increase in

both the wear rate, which is show from rotary tribometer testing [5] to be directly proportional to the

applied load, and also in the friction force, which is shown by reciprocating tribometer testing to be

proportional to the applied load [4].

FIG 14

Wear and Friction Map Generation

Wear and friction maps are generated from the FE solution data to indicate the likely wear and

friction across the surface area of the present panel design. The friction map is generated directly

from the FE solution data which incorporates the friction coefficient of 0.25 recorded during dry

sliding tribometer tests. Similarly, the wear map incorporates the wear coefficient data from rotary

tribometer testing to produce a realistic wear expectation under the various lubrication regimes

tested. Presented here is the dry sliding case, wear and friction patterns are similar for lubricated

cases.

FIG 15

Fig. 16 again shows a good correlation between the wear predicted by the FEA model and real world wear. This result indicates that the most severe panel wear is concentrated at the panel ends, followed by wear around the panel fixing holes and along the keel contact track, a result also seen on composite panels from slipway surveys.

This wear map represents the aligned contact case and mirrors the slipway survey observations of light panel end wear and delamination wear on slipway panels that were noted to be reasonably well aligned (less that 1mm height difference) with respect to neighbouring panels.

FIG 16

Two Panel Aligned Case

The one panel case is expanded to a two panel case to examine the stresses at the panel/panel interface. It is found that the two panel case closely mirrors the 1 panel case when the panels are modelled as being perfectly aligned to each another, with the wear on each panel similarly mirrored. It is now possible to expand this case to include some of the panel misalignment effects encountered on real world slipways.

FIG 17

TWO PANEL MISALIGNMENT MODELLING

From slipway site panel surveys it is seen that the height difference between panels can be up to 4mm, this may be an important influence on the wear and friction rates of slipway panels and so a number of simulations are run to model these misalignments between 0 and 5mm in height.

Three misalignment scenarios are modelled, one in which the slipway panels are assumed to have a parallel offset, both remaining in the same plane, and one where an angled offset is used, with the second panel angled in such a way as to give a panel height difference of 0 to 5mm at the panel interface. Site surveys indicate that both of these scenarios are present between slipway panels with the parallel panel offset scenario predominating, making up a total of 67% of the slipway panel interfaces surveyed. The remaining 33% of panels fit the angled offset scenario. A third scenario in which the second panel is skewed longitudinally with respect to the first is also modelled, survey data indicates that this scenario is present in 22% of cases, roughly equally occurring within both the parallel and the angled offset scenarios.

Small offsets of 0-1mm are modelled for the parallel case to further investigate the effects of panel misalignment, initial screening simulations indicate that results for both parallel and angled misalignment scenarios are similar for these small offset distances. In order to reduce analysis computation times the panel models are simplified by removing the fixing holes, the stresses around these features have already been modelled in the previous 1 and 2 panel analyses where it is shown that wear at these features, although still significant, is far less than at the panel interfaces and that the related contact stresses which contribute to friction forces are also far lower.

Parallel Panel Misalignment

The parallel panel misalignment scenario assumes that the two panels are offset while remaining

parallel by between 0 to 5mm as shown in the diagram below:

FIG 18

This model accounts for two thirds of the panels surveyed, with the average offset for all panels

being 0.82mm and the maximum being 4.06mm. Panel offsets of 0-1mm are also modelled for this

scenario to further clarify the panel interface behaviour for these small offset distances.

Angled Panel Misalignment

The parallel panel misalignment scenario assumes that the two panels are offset by between 0 and

5mm at the panel interface due to one panel lying at an angle to the slipway bed as shown below:

FIG 19

Site surveys indicate that this model accounts for around one third of slipway panels surveyed, with

the average offset angle for all panels being 0.04° and the maximum being 0.18°. These correspond

to panel interface offset heights of 0.80mm and 3.92mm respectively.

Skewed Panel Misalignment

The skewed panel misalignment assumes that the two panels are twisted longitudinally in relation to

each other as shown in the diagram below:

FIG 20

Site survey data indicates that this type of misalignment is present in 22% of panels, roughly equally occurring within both the parallel and angled offset scenario. Across all panels the average skewed offset angle is 0.11°, this corresponds to an offset height of 0.73mm. A maximum offset angle of 0.63° was also recorded; this corresponds to an offset height of 4.32mm. FE simulations are conducted using an offset height of 0-5mm as indicated by site survey data.

Results

Models are generated and simulations are completed for the three offset scenarios using simplified panel models for equivalent panel interface offsets of 0-5mm. The Von Mises maximum shear stress S_{max} is recorded as an indicator of the general load on the panels, as is the maximum deflection D_{max}. Results are presented for the parallel misalignment scenario below:

FIG 21

EXPECTED PANEL LIFESPAN FOR VARYING CONDITIONS

It is now possible to develop wear predictions and failure criteria based on the wear coefficients generated by the tribometer tests and on the stress concentrations from the FEA and slipway survey data.

The experimental tests, FEA simulations and slipway surveys conducted show that while the sliding wear coefficient between the lifeboat keel and the jute/phenolic composite is low enough to cause little concern under ideal sliding conditions, in the real world the stress concentration effects of even slight panel misalignments can result in a serious increase in slipway panel wear. Slipway surveys show that the average panel parallel offset was 0.88mm; with a maximum of over 4mm. FEA Analysis of the stress concentrations presented by this misalignment from the plane sliding case reveal that edge stresses resulting from this misalignment can increase up to 25 times that encountered in the perfectly aligned case. The contact pressure tests conducted above indicate a linear relationship between contact pressure and wear and so it would be reasonable to conclude that this would also result in a corresponding 25-fold increase in the wear rate at these high stress regions. If we then use the wear rates found from the tribometer tests and the maximum stress concentrations found from the FE Analysis for each misalignment case, the number of launches that will generate a wear scar depth of 19mm, the entire depth of the composite slipway panel can be calculated for these high stress regions.

TABLE 1

It is found that for the seawater lubricated case a wear scar depth equal to the 19mm panel thickness will occur after just 19 launches and recoveries. This would support the experience at Tenby where initial slipway hauling trials resulted in 10 launches and recoveries during the trial; this may well have contributed to the subsequent wear failure of slipway panels.

OBSERVATIONS

The tests and slipway surveys conducted above show that while the sliding wear coefficient between the lifeboat keel and the jute/phenolic composite is low enough to cause little cause for concern under ideal sliding conditions, in the real world even slight panel misalignments can result in a serious increase in slipway panel wear. This increase in wear due to panel misalignment would be sufficient to explain the high wear observed at Tenby and Padstow with the introduction of the new Tamar class lifeboat, particularly when the initial extended slipway line trials involving ten or more ascents/descents of the slipway under winch loading are considered. While these would have had little contribution to the wear under ideal conditions, panel misalignment effects show that they constitute over 50% of the number of launches required for the most seriously misaligned panels to fail.

As can be seen in the table above, the lubricant selection can have a significant impact on the wear rates for a misaligned panel. It should be noted however that previous reciprocating tribometer [4] testing indicates that for the consistently low friction required for successful lifeboat launch and recovery it is necessary to use some form of lubrication. It is also shown in the FE analysis that the increased edge stresses associated with panel misalignment will also result in increased friction at these points, further emphasising the need for lubrication to reduce friction. For this reason it is more sensible to examine and reduce the causes of slipway panel misalignment than to select a lubricant based on the high wear rates encountered with misaligned panels.

DISCUSSION

From the simulations it can be seen that there is a significant increase in the maximum Von Mises stresses, Friction forces and wear rate encountered as the height difference between panels increases.

This effect can be very significant, rising to 27 times the original stress and wear rates, and up to 78 times the original friction force for the perfectly aligned case compared with a 5mm angled offset and the 5mm parallel offset scenarios respectively. Maximum offsets of around 4mm have been observed on real world slipways for both parallel and angled scenarios, these would correspond to wear rates of 25 times the perfectly aligned case and friction forces of 62 times for the angled and parallel cases respectively. Even at an offset of 1mm, close to the mean offset observed for all slipway panels the stresses rise to over 11 times, wear rates to 12 times and friction rises to 18 times the perfectly aligned case. These results are extremely significant and could account for a good deal of the high wear and friction experienced during lifeboat recovery in the real world. The data from the skewed scenario also shows a significant effect with stresses at the panel interface reaching almost 28 times the perfectly aligned case.

Apparent Friction Coefficient Contribution

The contribution of panel misalignments to the apparent friction coefficient are shown in table 2 below for all offset scenarios tested.

These friction coefficients represent the apparent friction that would be indicated by winch loads calculated under the assumption of the lifeboat mass being evenly supported by the slipway panels. These do not represent an increase in the *actual* friction coefficient of the contact, but rather a consequence of the misrepresentation of the contact case as an evenly distributed load.

The results in table 1 indicate that panel misalignment is likely to have a significant adverse effect on local friction coefficients; with apparent friction exceeding unity at a panel offset distance of 2mm

for the parallel alignment case and of 5mm for the skewed and angled misalignment scenarios. This

may explain the stick-slip behaviour noted to occur during winch trials at Tenby and Padstow. These

simulations thus confirm the hypothesis that panel misalignment on real world slipways could be a

major factor in understanding the discrepancies between real and theoretical friction and wear rates

on lifeboat slipways. Survey data also confirms that such panel misalignments are present to the

extent that they may contribute significantly to the wear and friction observed along the whole

slipway. Panel misalignments are common to all slipways surveyed an are likely a result of the

fitting techniques involved, however, for large outdoor structures such as slipways it may well be

impractical to reduce alignment tolerances to wholly eliminate misalignment effects.

TABLE 2

CONCLUSIONS

These results show that panel misalignments are a significant contributor to the friction and wear of

slipway panels even at very small misalignments. This presents two major options to reduce this

effect, firstly the misalignments could be eliminated by setting strict panel fitting alignment

tolerances and secondly the design of the slipway panels could be modified in some way to reduce

the effects of panel misalignments on panel friction and wear.

Because of the difficulties likely to be involved in reducing real world systemic panel fitting

tolerances to below the ~1mm required for reliable slipway operation it is suggested that techniques

to reduce the effects of panel misalignments be investigated and this is to be the focus of future work

in this area.

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TABLE AND FIGURE CAPTIONS:

Fig. 1: Typical slipway launch: Tyne class lifeboat at Selsey moves down the plain sliding section of the slipway under its own weight

Fig. 2: Abrasive panel end wear: typical wear progression (left to right)

Fig. 3: Cracking panel end wear: wear scar progression: *Initially high contact stresses due to panel misalignment cause a surface crack to develop in the phenolic resin bulk of the composite, this then develops until it reaches the other side of the slipway panel, at this point the cracked area is held in place solely by the jute fibre matrix. The jute fibres subsequently fail, allowing a large section of slipway panel to break free*

Fig. 4: Panel end wear: cracking between fixing bolts

Fig. 5: Gouging wear from Tamar prototype

Fig. 6: 3rd body gouging wear

Fig. 7: Plane abrasive wear: exposed jute fibres

Fig. 8: Delamination wear: wear scar progression

Fig. 9: Delamination wear: detail

Fig. 10: Embedded Debris

Fig 11: Plan view of Von Mises Stresses on slipway panel from FEA simulation

Fig. 12: FEA simulation vs. typical worn composite panel section from Tenby slipway

Fig 13: Wear Scar developed using FE iterative element death techniques compared with real world example

Fig 14: simulation of wear progression over time on a slipway panel using FE iterative element death techniques

Fig 15: Friction map from FE simulation of 1 panel under normal keel loading: Friction force is shown in Newtons and is based on a friction coefficient of 0.25 from tribometer dry sliding tests

Fig. 16: Wear Depth/m sliding map from FE simulation of 1 panel under normal keel loading: Wear Depth is based on a wear coefficient of 3.7e-5 derived from rotary tribometer dry sliding tests. A worn panel from Tenby is shown for comparison

Fig. 17: Symmetrical Wear Scar developing on a perfectly aligned two panel model

Fig. 18: Parallel Panel Misalignment Model

Fig. 19: Angled Panel Misalignment Model

Fig. 20: Skewed Panel Misalignment Model

Fig. 21: Parallel Panel Offset Comparison

Table 1: Equivalent number of lifeboat launches/recoveries required to generate a 19mm wear scar on a 4mm parallel offset misaligned slipway panel by lubricant used

Table 2: Apparent friction coefficient contributions for modelled offset scenarios

Fig. 1: Typical slipway launch: Tyne class lifeboat at Selsey moves down the plain sliding section of the slipway under its own weight
225x120mm (115 x 150 DPI)

Fig. 2: Abrasive panel end wear: typical wear progression (left to right)
247x135mm (132 x 150 DPI)
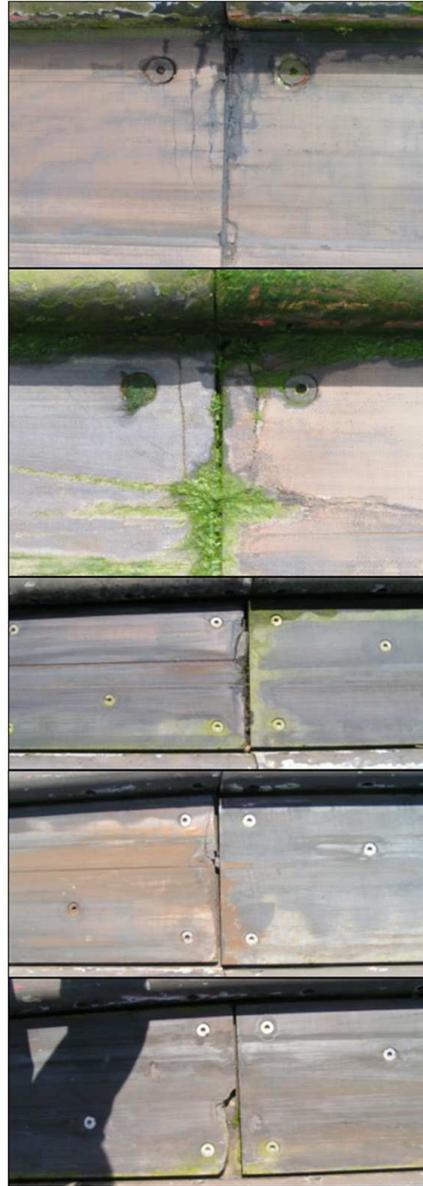
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Fig. 3: Cracking panel end wear: wear scar progression: Initially high contact stresses due to panel misalignment cause a surface crack to develop in the phenolic resin bulk of the composite, this then develops until it reaches the other side of the slipway panel, at this point the cracked area is held in place solely by the jute fibre matrix. The jute fibres subsequently fail, allowing a large section of slipway panel to break free
96x268mm (150 x 150 DPI)

Fig. 4: Panel end wear: cracking between fixing bolts
227x165mm (143 x 150 DPI)

Fig. 5: Gouging wear from Tamar prototype
238x109mm (150 x 150 DPI)

Fig. 6: 3rd body gouging wear
239x87mm (136 x 150 DPI)

Fig. 7: Plane abrasive wear: exposed jute fibres
230x86mm (141 x 150 DPI)

Fig. 8: Delamination wear: wear scar progression
112x375mm (150 x 150 DPI)

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Fig. 9: Delamination wear: detail
149x167mm (150 x 150 DPI)

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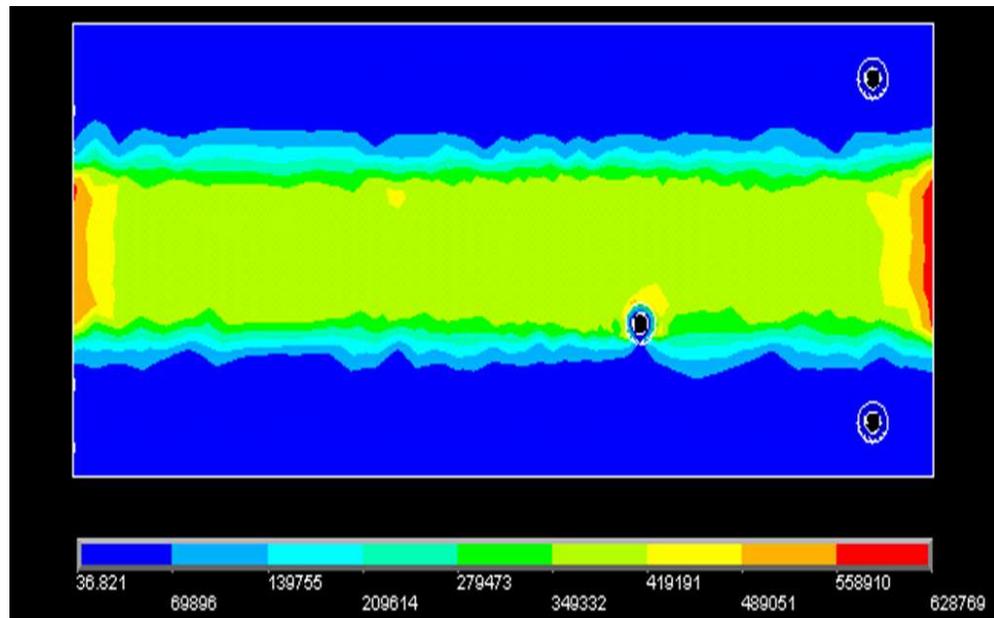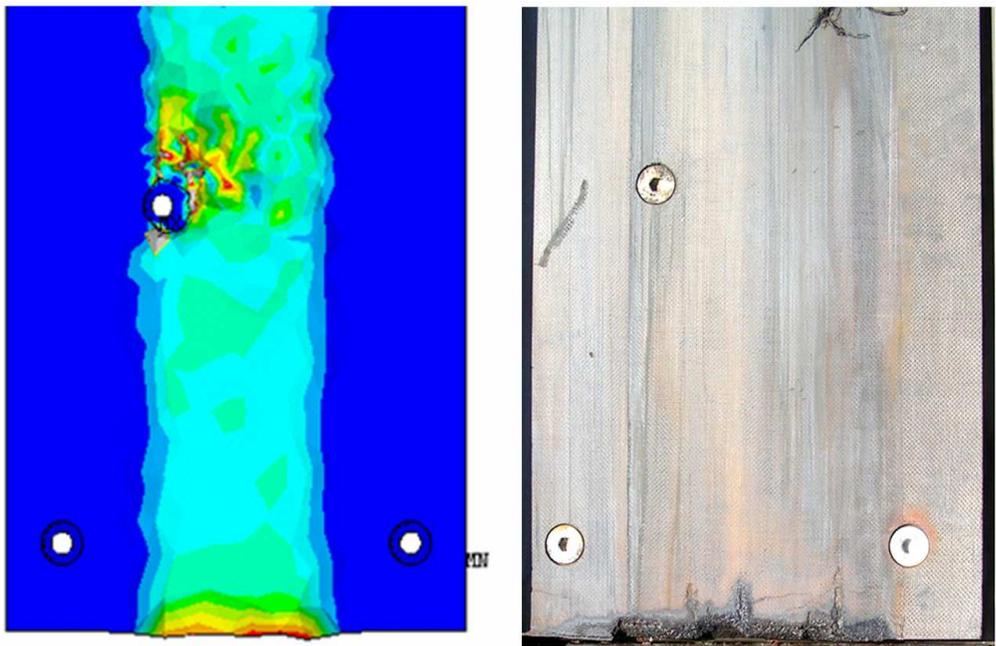60

Fig. 10: Embedded Debris
230x102mm (141 x 150 DPI)

Fig 11: Plan view of Von Mises Stresses on slipway panel from FEA simulation
236x107mm (110 x 150 DPI)

Fig. 12: FEA simulation vs. typical worn composite panel section from Tenby slipway
245x141mm (133 x 150 DPI)

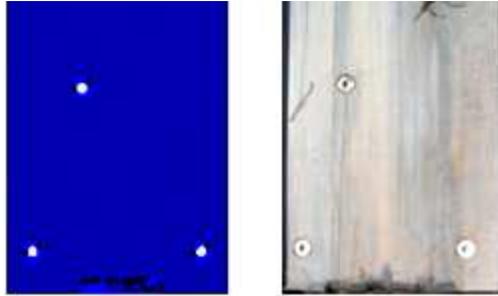Fig 13: Wear Scar developed using FE iterative element death techniques compared with real world
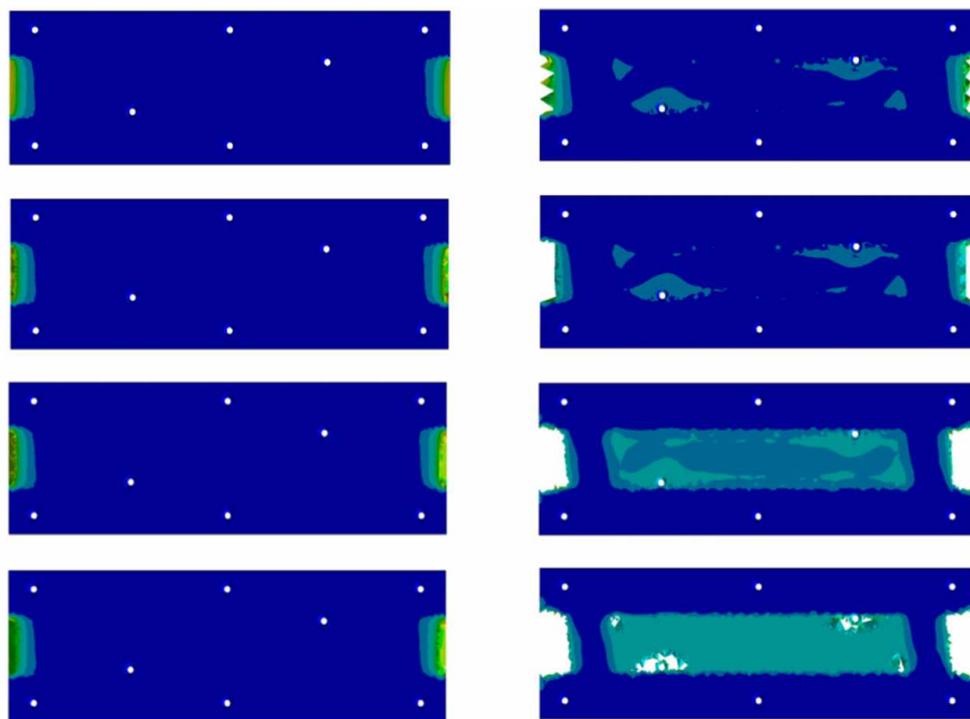example
219x129mm (29 x 29 DPI)

Fig 14: simulation of wear progression over time on a slipway panel using FE iterative element death techniques
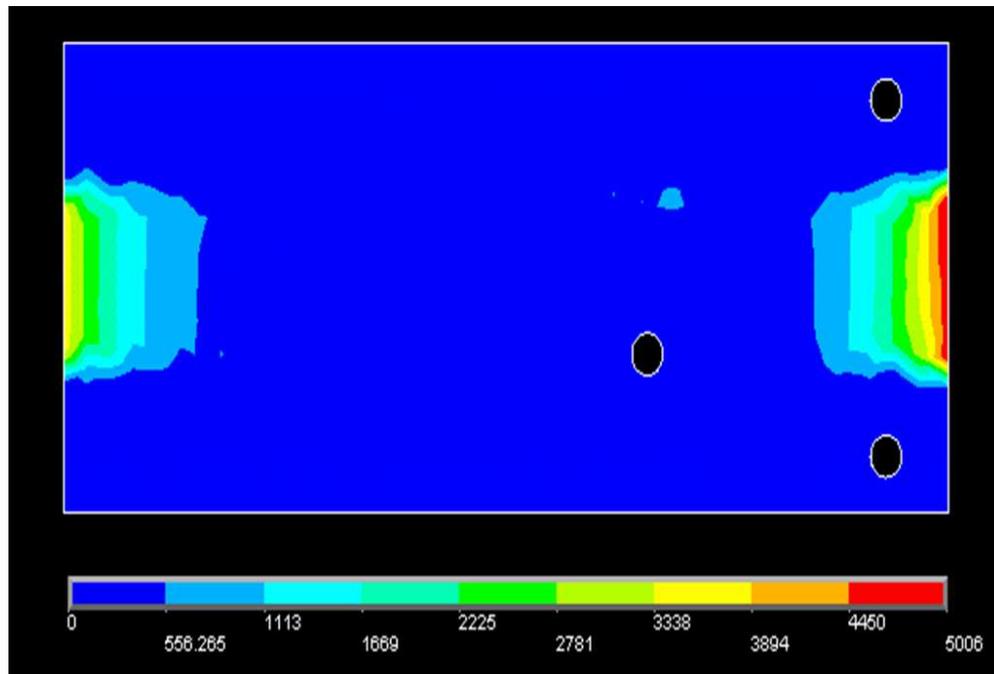235x155mm (138 x 150 DPI)

Fig 15: Friction map from FE simulation of 1 panel under normal keel loading: Friction force is shown in Newtons and is based on a friction coefficient of 0.25 from tribometer dry sliding tests
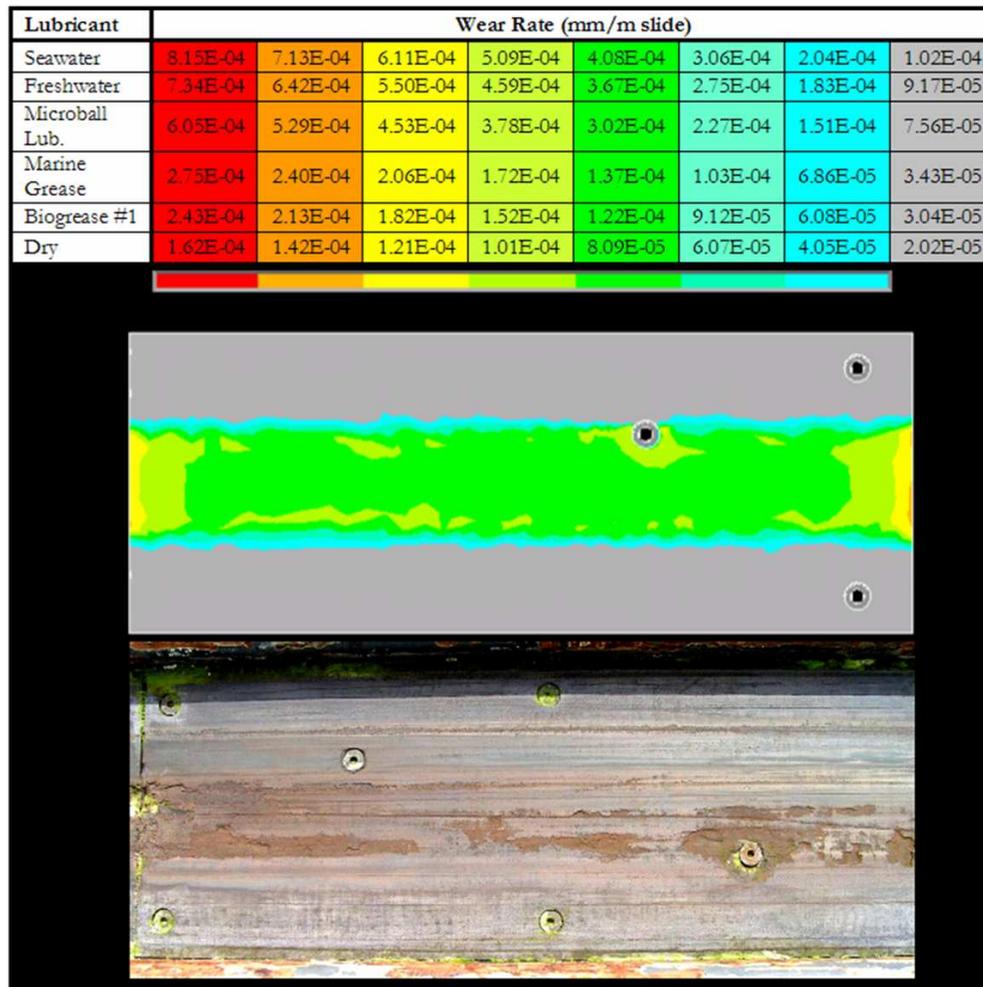235x117mm (111 x 150 DPI)

Lubricant	Wear Rate (mm/m slide)							
Seawater	8.15E-04	7.13E-04	6.11E-04	5.09E-04	4.08E-04	3.06E-04	2.04E-04	1.02E-04
Freshwater	7.34E-04	6.42E-04	5.50E-04	4.59E-04	3.67E-04	2.75E-04	1.83E-04	9.17E-05
Microball Lub.	6.05E-04	5.29E-04	4.53E-04	3.78E-04	3.02E-04	2.27E-04	1.51E-04	7.56E-05
Marine Grease	2.75E-04	2.40E-04	2.06E-04	1.72E-04	1.37E-04	1.03E-04	6.86E-05	3.43E-05
Biogrease #1	2.43E-04	2.13E-04	1.82E-04	1.52E-04	1.22E-04	9.12E-05	6.08E-05	3.04E-05
Dry	1.62E-04	1.42E-04	1.21E-04	1.01E-04	8.09E-05	6.07E-05	4.05E-05	2.02E-05

Fig. 16: Wear Depth/m sliding map from FE simulation of 1 panel under normal keel loading: Wear Depth is based on a wear coefficient of 3.7e-5 derived from rotary tribometer dry sliding tests. A worn panel from Tenby is shown for comparison
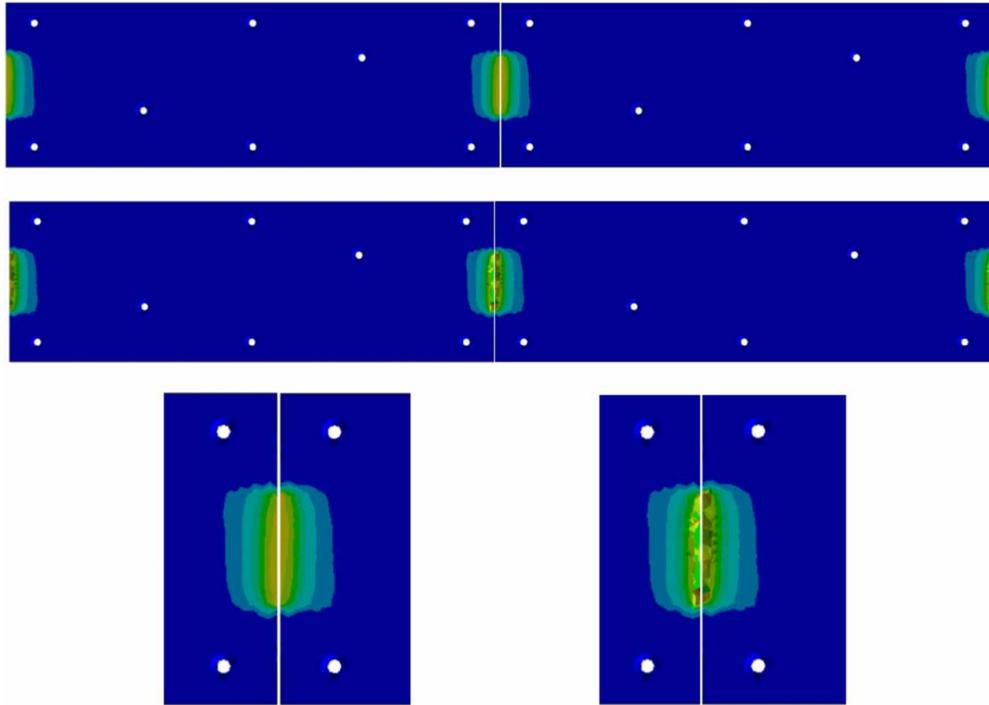197x196mm (150 x 150 DPI)

Fig. 17: Symmetrical Wear Scar developing on a perfectly aligned two panel model
225x154mm (144 x 150 DPI)

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Offset
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Fig. 18: Parallel Panel Misalignment Model
230x88mm (141 x 150 DPI)

Fig. 19: Angled Panel Misalignment Model
239x84mm (136 x 150 DPI)

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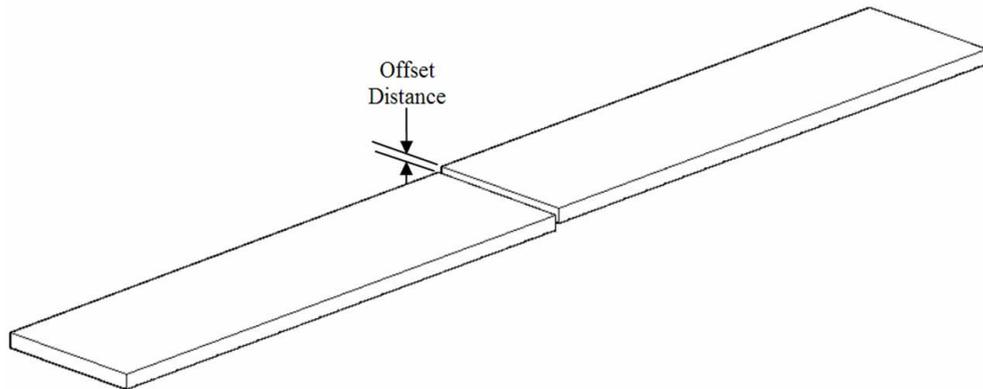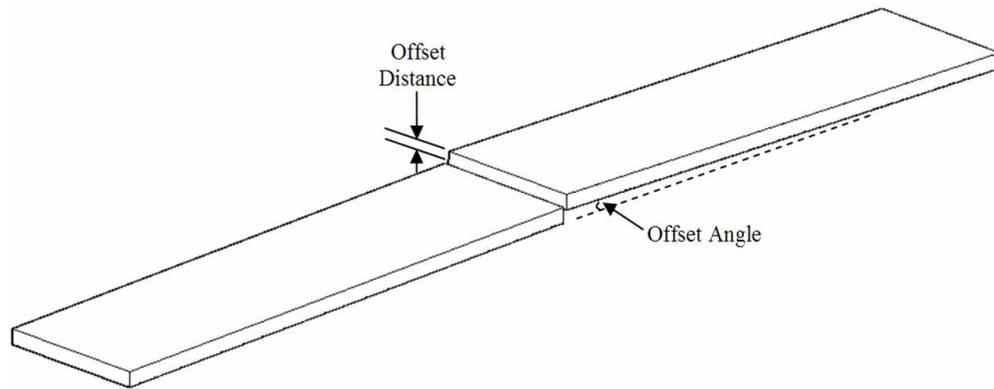43
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Fig. 20: Skewed Panel Misalignment Model
245x145mm (133 x 150 DPI)

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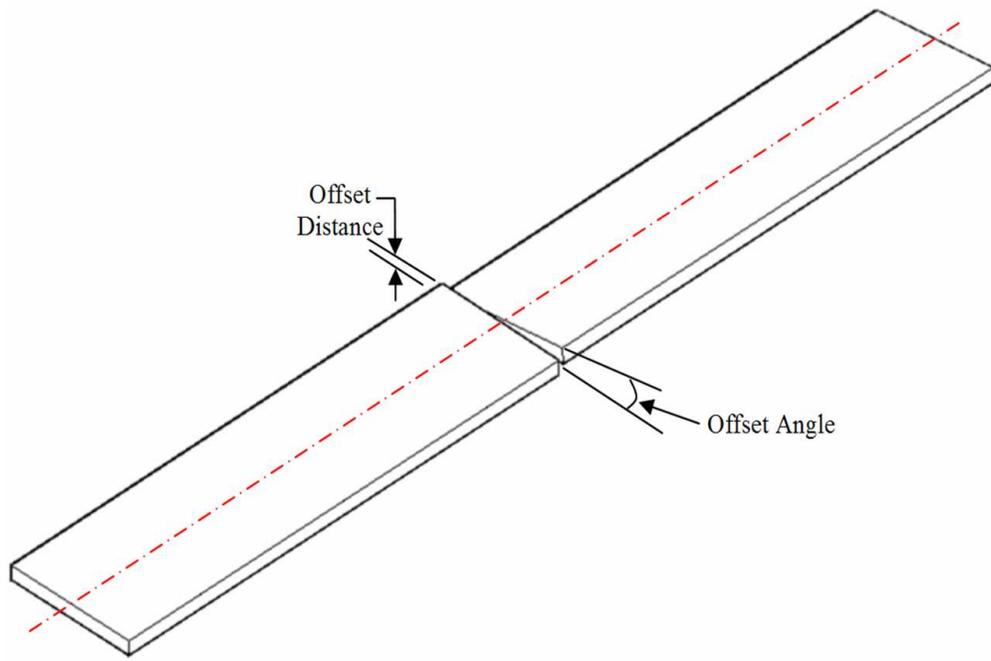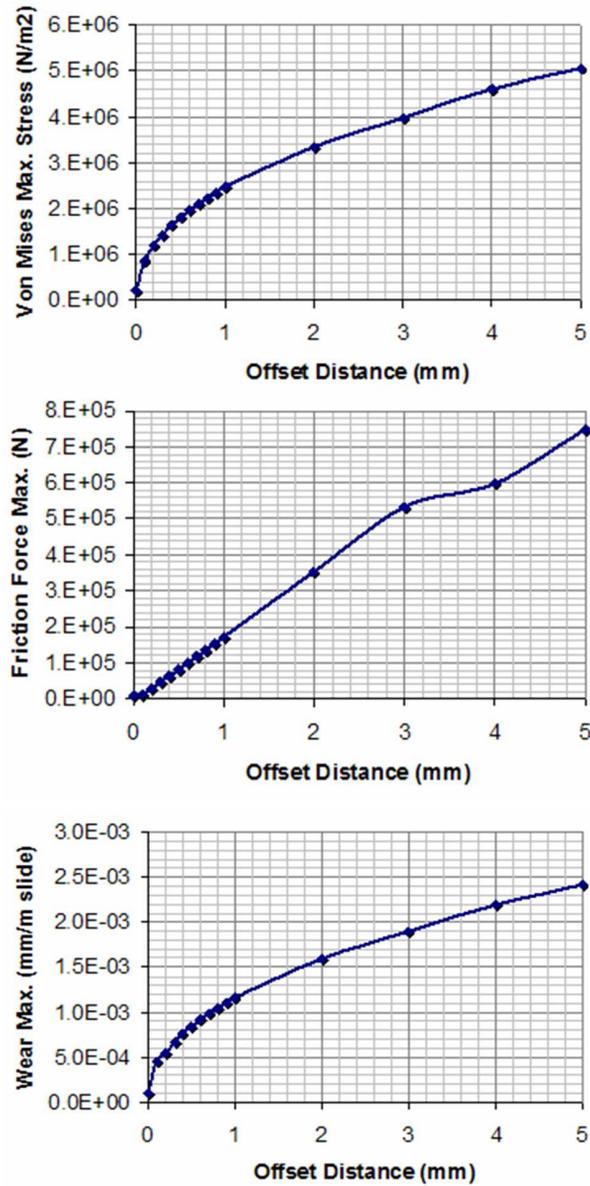42
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Fig. 21: Parallel Panel Offset Comparison
161x325mm (150 x 150 DPI)

Lubricant	Eq. Launches/Recoveries for 19mm Wear Scar Depth
Seawater	19.65
Freshwater	21.83
Silicon Microball Lub.	26.49
Marine Grease	58.35
Biogrease	65.86
Dry	98.94

Table 1: Equivalent number of lifeboat launches/recoveries required to generate a 19mm wear scar on a 4mm parallel offset misaligned slipway panel by lubricant used
114x51mm (72 x 72 DPI)

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Offset dist. (mm)	Friction Force Max.	Friction Coefficient Contribution
0	9.590E+03	0.028
0.1	1.195E+04	0.035
0.2	2.804E+04	0.082
0.3	4.536E+04	0.133
0.4	6.300E+04	0.184
0.5	8.096E+04	0.237
0.6	9.887E+04	0.290
0.7	1.172E+05	0.343
0.8	1.352E+05	0.396
0.9	1.534E+05	0.449
1	1.717E+05	0.503
2	3.534E+05	1.035
3	5.344E+05	1.565
4	5.984E+05	1.752
5	7.492E+05	2.194

Parallel Offset

Offset dist. (mm)	Friction Force Max.	Friction Coefficient Contribution
0	9.590E+03	0.028
1	8.428E+04	0.247
2	1.681E+05	0.492
3	2.534E+05	0.742
4	3.360E+05	0.984
5	4.150E+05	1.215

Angled Offset

Offset dist. (mm)	Friction Force Max.	Friction Coefficient Contribution
0	9.590E+03	0.028
1	5.587E+04	0.164
2	1.256E+05	0.368
3	1.989E+05	0.582
4	2.825E+05	0.827
5	3.560E+05	1.042

Skewed Offset

Table 2: Apparent friction coefficient contributions for modelled offset scenarios
315x637mm (72 x 72 DPI)