Tasman District Council

SWING MOORING DESIGN REPORT

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by

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1.0 INTRODUCTION

The Tasman District Council (TDC) has requested OCEL Consultants NZ Limited (OCEL) to review and update the earlier Swing Mooring Design Report issued in 2003. That report covered the development of swing mooring specifications for three different swing mooring locations in the Council's area:

- Sheltered open coast locations such as Torrent Bay in the Abel Tasman National Park
- Exposed open coast locations such as Stephens Bay and most of Golden Bay
- Exposed tidal locations such as the Mapua Channel.

While there is currently no national or regional marine industry standard for moorings in New Zealand the intent of the review is to formulate recommended practices and specifications that are compatible with the neighbouring Marlborough District Council (MDC) and the Nelson City Council (NCC) moorings and the Northland Regional Council's (NRC) Mooring Guidelines. The latter document was developed in collaboration with the Auckland Regional Council (ARC), Environment Waikato and mooring contractors to address the current 'vacuum' with regard to the lack of a national standard. This review will be consistent with the trend to best industry practice that is occurring in the industry – as evidenced by the NRC document - as the various regional authorities come into line. Environmental and subsea geotechnical conditions differ greatly between regions so there is no one size fits all specification, logical deviations supported by evidence/calculations will, be justifiable.

In addition to reflecting a trend to agreed best practice the review is to provide extra detail for the mooring specification with regard to specifying how mooring element connections are to be secured and what fair inspection intervals should be.

2.0 EXISTING MOORINGS AND EXPERIENCE

2.1 Existing Moorings

The 2003 OCEL report revised the minimum standard for the existing moorings in the TDC region and simplified and standardised the range of anchor block sizes to just two sizes - a 2 tonne air weight reinforced concrete anchor block and a 1 tonne reinforced concrete anchor block. Vessels up to 6 m length, irrespective of whether the moored vessel is a yacht or a powerboat, to be held by a 1 tonne block, vessels up to 12 m length to be held by a 2 tonne block. Vessels in excess of 12 m length have to be subject to design by a suitably experienced and qualified engineer. Often the design solution for vessels longer than 12 m would involve the use of two 2 tonne blocks joined by a chain bridle.

The standardisation of the block sizes recognised the fact that the anchor block sizes specified in the previous specification were undersize relative to the weights specified by other regional councils. While the smaller block sizes previously specified appeared to have performed well, OCEL was unaware of any failures at that time due to inadequate weight, increasing the block size increased the factor of safety against failure to in excess of 3. Increasing the factor of safety is prudent to the extent that it allows for greater variability in the seabed geotechnical conditions given that the mooring specifications have to cover a range of seabed conditions.

The revised standard also closely specified the block dimensions and the steel reinforcement required. The earlier standard gave a weight only. OCEL's engineering drawings for OCEL's standard 1, 2 and 4 tonne blocks, respectively Drawing Nos DR-1 tonne, DR-2 tonne and DR-4 tonne are attached as Appendix A with this report.

The depths in the TDC mooring locations can vary markedly, from up to 10 m below chart datum to less than 1 m below chart datum in an estuary or river channel. Some moorings such as those in the Moutere Inlet dry to up to 2 m above Chart Datum. The Mapua Channel mooring location is distinguished from the others by the speed of the tidal current to which the moored boats are subject. The maximum speed of the current is - reference the TDC letter of 27.08.03 - 3 m/second or approximately 6 knots. This current speed is high in OCEL's experience, higher than expected for an estuary type entrance. It would be useful to check the actual value at the moorings. The TDC harbour master has read current speeds up to 8 knots on the TDC patrol vessel speed log while the vessel was stationary against the transits in both the Mapua and Motueka channels during spring tide events. The moorings are not expected to be subject to these currents being generally off to the side of the channel.

2.2 Experience

It would appear on the basis of no known (to OCEL) major failures to date that the TDC moorings have performed adequately, both before and after the Mooring Specification revision in 2003. This is despite the TDC harbour master having observed that less than 10 of a total of close to 230 moorings in the TDC district are known to have a mooring block that meets or exceeds the TDC standard. The factor of safety against anchor failure - anchor dragging - is likely to be less than the normally accepted minimum of two (applicable where the seabed conditions are accurately known) for the earlier, pre 2003, Guideline, but is now in excess of 3 for the general case seabed conditions. However several of the smaller mooring blocks at Mapua have dragged in the last 4 years despite in one case the mooring being completely buried in shingle at the time of the last dive inspection. In this case the drag on the mooring was increased by a log hooked up on the vessel in a flood.

There have been failures from breakage of tackle during storms due to inadequate scope during storms or chafing. The mooring line components - as further noted in the following sections - are of similar size to the mooring line components in other long established mooring specifications. It is likely then that any failures will have been caused by deck fittings failing under load and mooring chains breaking as a consequence of inadequate maintenance.

3.0 MOORING ELEMENTS – COMPARISON WITH MOORING PRACTICE ELSEWHERE

3.1 Anchor Block Weight

The anchor weight blocks given in the TDC specifications are now, post 2003, identical to anchor weights given in the specifications of other regional councils in New Zealand. OCEL reviewed the mooring specifications for both Environment Canterbury (ECan) and the MDC some years ago and standardised on those block sizes. OCEL are also familiar with the specifications for other regional councils.

While a wide variety of types of weights have been used historically as deadweight anchors anchor block design has converged onto the use of concrete blocks and these are now standard. They can be supplied certificated to a design weight and standard. Steel railway wheels were common and earlier specified as part of the ARC Guidelines but are difficult to source these days given the high values for scrap steel. Non-standard highly variable elements such as engine blocks and forklift counterweights were also employed.

While the submerged weight of concrete block weights is 57% of the air weight, the submerged weight of steel weights is 87% of the air weight, which is an advantage but rather than use steel as a deadweight it is better and more economically employed as a purpose built anchor in passive earth pressure resisting plate form. The ARC has specified steel weights in the past but were part of the NRC mooring review which has adopted concrete block weights.

The TDC Guideline anchor block sizes specified for the length ranges up to 6 m and between 6 and 12 m, without discriminating between yachts and power boats, are the same weights specified for both the Nelson City and the Marlborough District councils. The NRC Mooring Guidelines also specify 1 and 2 tonne concrete anchor blocks but the vessel length categories are slightly different, up to 7 m and from 7 to 12 m.

The NRC Mooring Guidelines specify a 4 tonne weight for lengths in excess of 12 m. Although this appears to be open ended, elsewhere, in Table 8, it is noted that vessels in excess of 15 m length are subject to specific design requirements. OCEL's experience is that while a 4 tonne block could be used for vessels up to 18 m, depending on the seabed conditions, two 2 tonne blocks offer higher anchor capacity, and a consequently a higher factor of safety, principally because of the greater surface area available for passive earth pressure resistance.

Both the NCC and the MDC Guidelines allow for a 3 tonne block for vessels 12 – 16 m and a 4 tonne block for vessels 16 – 18 m. The ECan Mooring Guidelines specify 1 tonne anchor blocks for vessels up to 6 m, 2 tonne blocks for vessels 6 -12 m length and specific mooring design for vessels in excess of 12 m. The NRC length limit for specific design is 15 m. While OCEL has standard block designs for 3 and 4 tonne blocks, drawings attached in Appendix A – DR-3 tonne and DR-4 tonne – our recommendation is that the size limit be retained at 12 m for specific design to ensure that the factor of safety is the same across the length categories.

The environmental forces acting on vessels in the TDC region will not be markedly different from the forces acting on moored vessels in other areas of New Zealand - Mapua Channel aside - the same forces will be exerted on the mooring blocks for equivalent size vessels, hence the convergence on block size.

3.2 Mooring Line Length

The length of the mooring leg assembly is the sum of the lengths of the following constituent elements – ground chain, intermediate chain and the top rope connection to the moored vessel. The combined length of the mooring line elements for the TDC specification was confirmed at the time of the 2003 revision to be twice the depth of the water at mean high water spring (MHWS) tide. The length is similar to the length specifications for moorings elsewhere in New Zealand, in particular the ECan moorings and the MDC mooring but is less than for the ARC moorings. The principal differences between the guidelines lie in the different lengths of the individual elements. The NRC Guideline gives a maximum length of 3 times the depth at MHWS but notes that between 1.5 – 2 times the depth is often suitable.

For shallow moorings in the TDC area, in particular those that dry out at low tide, if the length of the ground chain is set equal to the vessel length the ground chain length will be greater than twice the depth at MHWS. The chain length can be limited to twice the depth at MHWS in these cases to keep the swing radius reasonable.

3.2.1 Ground Chain

OCEL's recommendation is that the length of the ground chain is to be a minimum of 6 m or 1/3 of the depth at MHWS. In the 2003 revision the length was set at equal to the length of the vessel but this becomes excessive for the larger vessels. The NCC and MDC Guidelines specify that the length of the ground chain should be a minimum of 1/3 of the depth at MHWS. The OCEL recommendation is the same but sets a minimum 6 m length for 6 – 12 m length vessels which will be conservative for almost all moorings because that implies a water depth of 18 m at MHWS. The length of the ground chain can be reduced to 4 m for vessels up to 6 m length. The NRC Guideline gives a minimum length of 5 m for vessels over 7 m length.

The ground chain is the principal energy absorbing component in heavy weather. The heavier and longer it is the less the wear on the mooring block eye and the less the vertical uplift on the mooring block. Along with the intermediate chain the chain catenary action gives the mooring line elasticity and reduces shock loading on the vessel attachment points. Catenary analyses of typical moorings undertaken by OCEL show that all moorings become tight at maximum load with some uplift on the mooring block, as discussed in the mooring line analysis section. The longer the ground chain the less the uplift. If the ground chain can reach surface then it can be used to lift the mooring block for inspection, which increases the safety of the operation.

The size or diameter of the ground chain specified is the same as specified for the NCC and MDC Mooring Guidelines. 24 mm for vessels under 6 m length, 32 mm for vessels 6 – 12 m length and 38 mm for vessels in excess of 12 m. The NRC Guideline gives 35 – 38 mm for vessels 7 – 12 m length and 20 mm minimum for vessels under 7 m length.

3.2.2 Intermediate Chain

The length of the intermediate chain for the TDC Guideline is 1.5 times the depth at MHWS. This makes the total length of chain – ground + intermediate – for the TDC Guidelines longer than for the equivalent NCC, NRC and MDC moorings. The NRC Guidelines specify a minimum length for the combined chain length – ground chain plus intermediate chain = 1.1 times the depth at MHWS.

The additional, relative to the other guidelines, length of chain in the TDC moorings is beneficial in reducing uplift on the mooring block and minimising shock-loading. The minimum size of the intermediate chain used is set at 16 mm for vessels under 6 m length. Lesser sizes wear faster. The size for the 6 – 12 m length range is set at 20 mm. These sizes conform with the NRC, NCC and MDC Guidelines.

As for the ground chain the load capacity of the chain is well in excess of what is needed, the weight is beneficial for the mooring characteristics.

3.2.3 Top Rope

This connects the mooring leg to the vessel and is exposed to wear from the fairleads and the vessel structure. Anti-chafe protection is important and should be provided by UV resistant reinforced hose securely fitted to the rope so that it does not slip and wear on the rope itself.

The length of the rope specified for the TDC Guidelines is the same as for the NRC Guideline – to suit or a minimum of 2.5 m. The NCC and MDC Guidelines specify the length to be equal to the depth at MHWS, close to half the length of the mooring leg. The TDC Guideline allows for greater elasticity provided by catenary chain action. Only nylon rope is to be used for the top rope to avoid the hazard of floating ropes fouling the propellers of passing vessels. This is particularly important in areas such as Glasgows Bay, where water taxis have to pass through the mooring area to reach their DOC defined landing point, and at Mapua where a fouled vessel with low freeboard could be at risk of foundering stern to the current. It is useful to use nylon rope for the top rope because of its greater elasticity relative to polypropylene ropes. Diameter 20 mm rope for vessels under 6 m length, 24 mm for vessels 6 – 12 m.

3.2.4 Connecting Elements

Shackles are used to connect the mooring leg elements in line. They must be secured tight following assembly of the leg, either by the preferred method of welding or secured using 2 mm diameter stainless steel mousing wire. Spot or tack welding is not acceptable. The shackle pin head is to be fully welded around the pin shoulder with deep penetrating compatible electrodes. Welding is preferred unless it is not practical to lift the block to surface for subsequent inspections. In that case the use of a moused or pinned bolt will be needed to enable a diver to undertake checks and replacements in situ. Certified shackles to be used. Some shackles utilise a bolt in place of a shackle pin to close the shackle. A stainless steel split pin must be used to secure the nut even if a nylock-type nut is used. It is recommended that an anti-seizelanti-corrosive compound such as Res-Q-Steel be used on the bolt or pin thread.

The shackle sizes specified for the TDC Guideline are as follows:

> Ground chain connection to the block - 32 mm for vessels < 6 m, 38 mm vessels 6 – 12 m.
> Intermediate chain connection - 22 mm for vessels 6 m, 26 mm for vessels 6 – 12 m.

These shackle sizes are consistent with the NRC, NCC and MDC Guidelines.

A swivel is recommended at the top of the intermediate chain to avoid the twin perils of 'binding up, or 'twisting down'. 'Bind down' refers to the top chain twisting to pull the mooring down, 'twist down', refers to the situation where the top rope can either un-lay or twist up and break. Swivel sizes - 22 mm for the vessels under 6 m length, 26 mm for vessels 6 – 12 m length.

3.2.5 Corrosion

Avoid the use of dissimilar metals in the mooring leg - other than the use of stainless steel wire for mousing shackles. It is recommended that a 1.5 kg anode be welded to the swivel. Alternatively bolt to the chain below the swivel. A large number of the mooring blocks used in Mapua and the Abel Tasman feature the use of stainless steel mooring eyes to which the mooring leg is connected by a black shackle – in apparent contradiction of the instruction to not use dissimilar metals. This is acceptable because of the criticality of the block mooring eye. If the mooring eye fails the block has to be replaced. It is easier to replace the black shackle. The stainless steel mooring eye will not corrode, the black shackle will, but not at an accelerated rate in between regular inspections.

4.0 REVISED GUIDELINE SPECIFICATION

The recommended mooring specification is as detailed in Table 1. This represents a relatively minor revision of the 2003 revision and is designed to bring the Guidelines further, but not fully, in line with the NRC Guidelines in pursuit of a national best industry practice. The differences with the NRC Guidelines, and the NCC and MDC Guidelines relate to the length of chain used. Given that some of the TDC locations are relatively exposed the use of longer chain elements is appropriate for the particular circumstances of the TDC moorings.

Construction Specifications

Mooring Class	Vessel Length	Block Weight	Ground Chain Diameter (mm)	Mooring Chain Diameter (mm)	Rope Diameter (mm)
Class A	Up to 6 metres	1 tonne	24	16	20
Class B	6 – 12 metres	2 tonnes	32	20	20
Class C	> 12 metres	Vessel specific design by Chartered Professional Engineer with experience in mooring structures			

1. Length of ground chain 6 m and not less than 1/3 depth of water at mean high water springs (MHWS).
2. Length of intermediate chain 1.5 x depth at MHWS.
3. Length of the rope to suit the vessel but not less than 2.5 m. Total length of the mooring leg – ground chain + intermediate chain + rope – to be not less than twice water depth at MHWS.
4. Welding shackles is generally the preferred method of securing shackles closed. Mousing shackles with 2 mm diameter stainless wire is an acceptable alternative. Threads should be coated with an anti-corrosive compound such as Res-Q-Steel or similar.
5. Swivels must be used, the size of the swivel to be commensurate with that of the chain.
6. Anodes may be used at the mooring provider's discretion.
7. All mooring blocks must be designed by a Chartered Professional Engineer with expertise in mooring structures and be made to those specifications.
8. Similar metals are to be used throughout. However, if the block eye is stainless steel then a black shackle may be used with inspection intervals adjusted accordingly.
9. Moorings of different design and/or manufacture will be considered on a case by case basis. As a minimum, such moorings must be supported by appropriate Chartered Professional Engineer design drawings and certification.

Mooring Inspection Requirements

1. Moorings should be recovered to the water surface for the purpose of inspection. Where this is not practical periodic inspections may be performed by a suitably qualified and experienced diver and the block lifted once every ten years for a physical check.
2. All tackle is to be replaced at 10% wear.
3. Moorings must be inspected at intervals not exceeding 2 years.
4. A completed mooring inspection report must be forwarded to the Harbourmaster (who will then update compliance records for the Consents Department) not later than 14 days after the inspection.

Table No 1

CAVEAT

MOORING CONSTRUCTION GUIDELINES

These guidelines are not intended as a substitute for the need to address the particular seabed and weather conditions encountered at each individual mooring site. It is recommended that you consult a professional mooring provider and/or Chartered Professional Engineer for site–specific advice tailored for the vessel/s to be moored.

Be aware that risk cannot be completely eliminated in the mooring of a vessel.

Council does not accept any responsibility for any loss or damage which may occur as a consequence of the use of these guidelines or otherwise.

5.0 INSPECTION REGIME

The inspection regime has been adopted from the NRC Guidelines which represent a succinct summary of the requirements. The acceptable wear however has been simplified at 10% for all components.

The inspection, care and maintenance of all the mooring components is the responsibility of the mooring owner. The mooring owner must arrange and pay for the inspections and any replacement parts.
The frequency of the inspections shall be determined by the harbourmaster. In determining inspection periods the following shall be taken into account:

a. Mooring type
b. Location
c. Usage
d. Any history of failure of that or similar moorings
e. Climatic events.

An inspection at least every 2 years is recommended using an inspector listed and approved by the harbourmaster. An agreement should be drawn up between the mooring contractor and the harbourmaster. The mooring contractor is to hold the public liability insurance.

A copy of the maintenance/service report should be forwarded to the harbourmaster.

If a mooring does not comply with the minimum specifications consideration shall be given by the harbourmaster, in consultant with the contractor and or designer, to downgrade the mooring's rating to a smaller vessel. If required the mooring license can be suspended, and the mooring is not to be used until it is upgraded to the minimum required standards.

If the non-conformity is not rectified within 60 days the mooring may be considered abandoned, and can be removed by the harbourmaster at the owners cost.

All mooring line elements to be replaced at 10% wear. Other guidelines use 20% however if the inspection interval is 2 years the mooring component could have 40% wear at the next inspection – if it has survived that long.

5.1 Inspection Methods

There are two methods of mooring inspections:

- In Water: Conducted by divers without removing the mooring. This is used often where the mooring block is a large size, or too heavy for the local barge to lift or, where it is preferable to avoid disrupting the passive earth resistance of a well embedded block that is less than 10 years old. The divers used would have to be approved by the harbourmaster to carry out the work.
- Raising: The entire mooring is brought onboard the vessel and inspected, repaired and replaced as required. This option is preferred in that a photographic record of the state of the mooring elements is obtained but recovering the mooring disrupts the passive earth pressure resistance. Care must be taken to ensure that the block is set back into the seabed to engage passive earth pressure resistance.

Each part of the mooring structure assembly should be inspected and the following information recorded.

5.2 Information to be Recorded

Chain
- Clean off and ensure all parts are inspected
- Record length and diameter of most worn part
- Check for and record any manufacturer's markings
- Check for pitting, measure diameter and depth of any pits found, and record results

- (Chain life may be able to be extended by removing a worn end link.)

Components
- Record components overall length and diameter
- Report any loose, broken or missing parts
- Record any manufacturers markings
- Measure least diameter of shackle pins, inspect security of the pins.

Swivel
- Record components overall length and diameter and condition.

Buoy
- Record buoy type, position and any markings. Comparison should be made to the original buoy GPS position and sight lines or bearings to determine if drag has occurred.
- Record buoy overall condition
- Identify each component attached to buoy (ie shackles, rings etc) and measure diameter of each
- Check and report on condition of buoy mooring arrangements (diameter, plate thickness etc).

A sample inspection form is attached in Appendix B. Any parts replaced should be recorded on the form with dimensions of new part.

6.0 ANCHOR RESISTANCE

The resistance of a deadweight anchor block to mooring forces has two principal components - friction and passive earth pressure resistance. The latter is mobilised by sinking the anchor block into the seabed and is normally the major component of the total resistance.

The anchor resistance is also dependent on the nature of the seabed soil and its strength. OCEL is not completely familiar with the seabed conditions within the mooring areas designated by the TDC and has had to assume soil strength characteristics. The anchor resistance figures developed in the following sections are conservatively based on soft marine mud, undrained shear strength equal to 10 kPa.

Failure of the mooring by exceeding the soil capacity for peak loading is not catastrophic. The anchor will drag and provided that sufficient space is available and that the anchor capacity is only momentarily exceeded in response to peak forces then the limited anchor dragging will not have disastrous consequences. Breakage of the mooring line elements is potentially catastrophic. The dimensions of the mooring line elements given in the TDC specification however are similar to those in other regional council requirements. Incipient failure or dragging under peak load does not affect the serviceability of the mooring.

6.1 Methodology

To check the adequacy of the moorings and the degree of safety offered against failure the loads acting on the moored vessels have first to be calculated and the resultant force acting on each vessel compared with the ultimate resistance provided by the anchor. The factors of safety specified for the mooring system components can then be set taking into account the consequences of failure of each component. The failure of any of the line elements or connectors for example can be taken as catastrophic because the vessel is set adrift whereas dragging of the anchor can be accorded a lower factor of safety reflecting the fact that the vessel is not set free.

The loads acting on a moored vessel can be divided into quasi-static or QS loads and total dynamic or TD loads. The loads in the mooring line due to wind, swell and current are QS loads. The system tends to move at a relatively low frequency, low with respect to the wave and swell frequencies. On top of the QS loads there are individual wave forces causing a high frequency motion which can produce shock loading in the case of inelastic or stiff moorings. These shock loadings are more important for the anchor line components than the anchor itself because of their sharp transient nature.

The individual environmental forces acting on moored vessels are computed in the following sections, combined and compared with the calculated anchor resistance to derive a factor of safety for each mooring. The results are presented in a spread sheet format Appendix C. The anchor block resistance figures are based on the anchor blocks, detailed in the drawings contained in Appendix A.

6.2 Environmental Forces

The starting point for the review was to calculate the QS environmental forces acting on the different vessels categorised to length as mooring classes. For each mooring class the maximum length vessel in that class was considered. The total environmental force has three components - wind load, current load and wave load. Each environmental load will be considered separately in the following.

6.3 Wind Load

The design wind speeds used for the calculation of the wind loads were taken from the New Zealand Standard Loading Code NZS 4203:1984. The wind speed given in the Standard is the 3 second gust speed. Wind loads on moored vessels relate to a design wind pressure based on a steady state wind rather than wind gusts. The 3 second gust speed was adjusted to give the sustained wind over a longer period, taken as 30 seconds, using a logarithmic relationship of the form:

$$V(T) = V_g.(1 - A.\log_{10}(T/T_g))$$

Where:

- V_g is the 3 second gust speed
- $V(T)$ is the sustained wind speed over period T
- T_g is the period of the gust = 3 seconds
- A is a constant taken at .185 for the TDC region in the absence of more accurate data.

The longer time period, 30 seconds, versus the 3 second period used in building design reflects the fact that a mooring is relatively elastic, the elasticity provided by the mooring chain catenary and any nylon rope elements in the mooring. The wind force acts on the vessel and the vessel moves in response before the mooring line comes up hard. A longer period of 1 minute could have been used but the swing moorings generally used are relatively stiff on account of the need to restrict the swing radius. The design wind pressure was calculated in accordance with AS 3962, the Australian Code - Guidelines for the Design of Marinas.

6.4 Current Load

The load exerted by a current on a moored vessel has two components:

- Form drag associated with the loading of surfaces perpendicular to the current direction.
- Surface drag associated with friction on surfaces parallel to the current direction.

The dominant force component for small craft is form drag.

The current load acting on each vessel was calculated using a form drag equation taken from AS 3962. The tidal current speed was conservatively taken at .5 knots for the TDC mooring areas outside of the Mapua Channel where a maximum current velocity of 6 knots was used. The tidal current speeds used represent a maximum for the TDC mooring locations. A wind driven surface current was added to the tidal current to derive a total current.

6.5 Wave Load

Wave action is a random phenomenon which induces two types of load on moored vessels:

- A permanent drift load, a QS type force.
- A load which varies with time according to the wave frequency causing irresistible movements of the vessel and shock loading in the mooring line, TD type force.

The QS wave load on the vessels was calculated using an empirical relationship for wave drift forces. This load, as the term quasi static suggests, is a relatively constant force. The moored vessels are free to move on their moorings in response to the wave forces. The intense TD type forces initiate movement. The driving force can be taken as the Froude Krylov force - obtained by integrating the dynamic wave pressure over the submerged surface of the vessel - acting on the vessel. This force is used in the equation of motion for the moored vessel, it is not the force directly applied to the mooring system. The moored vessel will be aligned with the direction of the prevailing weather, given that it can weather vane about its mooring, and the resulting motion will be a surge, fore and aft, motion with a natural frequency much lower than the wave frequency. For a vessel length less than the wave length the amplitude of the surge motion is close to the amplitude of the wave motion - amplitude = .5 x the wave height.
The mooring locations vary from sheltered to open sea conditions however open sea conditions in Tasman Bay are not as severe as elsewhere in New Zealand. Tasman Bay is one of the most sheltered - from the point of view of wave action - big, open embayments on the New Zealand coastline. The Bay is sheltered from the persistent long period south westerly ocean swell found in the high wave energy environment of the Tasman Sea, being open only to the north. The principal source of wave energy in Tasman Bay is from locally generated waves in the fetch to the north/north east of the site. Swell conditions are rare, the waves to which the moored vessels will be subject will generally be short period steep, locally generated wind waves.

The significance of the wave period is that the wave length of swell is, even in shallow water, much longer than the length of the moored boats, the boats ride with the swell, the amplitude of the vertical heave motion is essentially the same as the swell amplitude. The force driving the moored vessel in these conditions is equivalent to the downslope component of the weight of the vessel on the slope produced by the swell. For a 10 second period swell and a swell wave height of 1 m this can amount to a force close to 1 tonne for a 20 tonne displacement vessel. The excursion distance of the vessel is much greater than for the locally generated wind waves because of the increased water particle orbital excursion distance in a swell. These factors explain the damage to vessel mooring fixings in swell conditions. For vessels moored in locations that may be subject to swell conditions the length of the mooring line will be increased to increase the elasticity of the mooring.

Locally generated storm waves have wave lengths not much longer than the lengths of the larger of the moored boats. For a vessel of the same wave length as the storm wave the net force on the boat is close to zero, the forward motion of the water particles under the crest of the wave is counteracted by the reverse motion under the trough. The storm waves are short and steep and reflect off and impact on the moored vessel but the resulting loads are short sharp shock rather than sustained loads.

6.6 Total Environmental Force

The constituent QS forces acting on each vessel length category are presented in spread sheet form attached as Appendix C. The total force is given as the sum of the constituent forces. The tidal current force acting on vessels moored in the Mapua Channel is calculated separately on the spread sheet. The concurrent wind force is maintained the same for all the TDC mooring locations which will be conservative given that some of the locations will be sheltered and open sea conditions will not apply.

The wind force is generally the predominant force except for the Mapua Channel location where the tidal current force can attain a larger magnitude. The current force calculation was over conservative for yachts in the first edition of the spread sheet because the cross section area exposed to current was taken as the beam multiplied by the draft. That over conservatism has been corrected in the latest revision attached with this report.

Within the same length class there are significant differences in the total environmental force on yachts and launches. This is a direct consequence of the difference in windage areas. The areas, which were taken from AS 3962, vary by a factor of two for vessels in excess of 18 m. Rather than separate the vessels into separate classes for yachts and launches it is more convenient administratively to retain the length category. The factors of safety vary within the class but are still well above the minimum.

6.7 Resistance and Safety Factors

The anchor resistance capacity, based on the revised anchor dimensions and weight and on conservative assumptions of the seabed soil strength, is also calculated on the spread sheet. The factor of safety is derived by dividing the resistance capacity by the total environmental force. The resulting factors of safety are satisfactory for the mooring location areas outside the Mapua Channel notwithstanding the low soil strengths assumed. As is apparent from the spread sheet the wind force is the predominant environmental force on a moored vessel - with the exception of areas such as the Mapua Channel. The wave induced forces are low provided there is sufficient elasticity in the mooring. The use of relatively long chain lengths in the mooring leg assists this. There is then no strong distinction between the sheltered and exposed open coast mooring locations, the same mooring arrangement will be satisfactory in both. It has to be assumed that both general areas will experience the same wind strength.

The safety factors for the Mapua Channel location are based on the blocks being set into the relatively stiff gravelly seabed in the Mapua Channel. Soft marine mud and sand size material is not stable in currents of 6 knots, the bottom has to be either hard cohesive material or non cohesive material of sufficient size to be stable in the flow. The revised anchor blocks set into the bottom of the channel are capable, as proven by experience, of resisting the applied environmental forces but safety factor against dragging is relatively low at less than 2 in some cases, based on an assumption of the soil strength parameters. There is an inherent contradiction the blocks have to be set into the seabed but if the seabed is hard this is difficult to do. Yet the blocks have been set into the seabed at Mapua and they do hold. This contradiction can only be resolved by a detailed investigation of the bottom sediment in the Mapua channel to determine its actual properties.

7.0 ANCHORS - Alternatives

7.1 General

The environmental forces acting on the moored vessels are resisted by the anchor - and the friction of the mooring chain still on the seabed. The forces considered for the anchor are the QS forces rather than the TD loads. The short shock loads applied by the latter are resisted by suction and soil dilatancy effects that cannot be counted on for sustained resistance. The loads are generally too short to initiate movement of the anchor taking into account these effects and the inertia of the anchor.

7.2 Gravity Anchors

Gravity anchors are normally used for the swing moorings in New Zealand, principally because they can take more loads from any direction in the horizontal plane. Gravity anchors are the simplest type of anchor deriving their capacity from a combination of frictional resistance to sliding and passive earth pressure resistance arising from embedment or burial. The passive earth pressure resistance component is normally the largest component of the anchor resistance capacity. The sliding resistance or Coulomb type friction can be low on soft seabed material. The coefficient of friction, μ, can be low as .2 to .3, the available resistance is then μ times the submerged weight. The coefficient on sand is approximately .7.

For a 2000 kg concrete weight the submerged weight is 1146 kg. The resistance can then be as low as 2.3 kN for the case of a weight on a thin veneer of soft material overlaying stiffer material. By contrast if the mooring block (2000 kg) is embedded in even a soft silt seabed, undrained cohesive strength taken at cu = 10 kPa, the available passive earth pressure resistance is 12 kN plus the shear resistance across the base calculated at 22.5 kN, total 34.5 kN. The weights need to be buried in the seabed to develop both passive earth pressure resistance and base shear resistance. The anchor must also be sunk far enough into the seabed to avoid coming in to conflict with the keel of the moored vessel as it swings on the mooring.

An important part of the mooring installation and subsequent inspections must be ensuring that the anchor block is buried or embedded in the seabed so that it can develop passive earth pressure.

The calculations of anchor capacity incorporated in the spread sheet are based on the 2 and 1 tonne air weight anchors shown in Drawing Nos DR-1 tonne and 2 tonne Appendix A.

The basic swing mooring consists of an anchor block or blocks (connected by a chain bridle) with a chain mooring leg and nylon top rope holding one vessel. A variant of the system which enables boats to be moored closer together uses a seabed ground chain connected between gravity anchors at either end of a line of moored vessels. A ground chain seabed grid system with gravity anchors both within and at the corners of the grid can also be used. The individual vessels are attached to chain risers spaced at intervals along the ground chain. The seabed ground chain system has been used in the TDC district at Tarakohe harbour Golden Bay for the moorings inside the outer breakwater arms. The system requires specific design for each location but is a smart system in that it efficiently utilises the available mooring space. The system must be designed to take the quasi static (QS) wind and current loads acting on all the vessels concurrent as a constant QS load. The wave and snatch loadings on each vessel will be random and do not have to be considered as acting concurrently for the complete system.

7.3 Alternative Anchor Systems

While only gravity block anchors have been employed there are alternative anchor systems available, some of which will be considered here.

7.4 Marine Anchors

The mooring locations provide good holding for conventional marine anchors, such as Danforth anchors, provided that the anchors are well embedded in the seabed. A whole range of marine anchor types are available, mostly variations on the stockless Danforth theme. The various anchor types are usually classified based upon certain characteristics such as fluke area, shank type and number - single or double - and the presence or absence of stabilisers. A new generation of anchors known as high holding power (HHP) anchors has been developed principally for use in the offshore oil industry. These are the most efficient anchors in terms of the holding power to anchor weight ratio, reliable holding power up to 20 times (and higher for light anchors) the anchor weight can be achieved. The flukes are set at a fixed angle to the shank and the shank is elbowed, similar to Bruce type anchors, to allow deep penetration into the seabed. Because the moorings are swing moorings three anchors connected by ground chain legs to the central mooring point would be required. This would make them more expensive than an equivalent deadweight/passive earth pressure mooring even allowing for the use of lighter vessels to carry out the installation of the mooring. The use of the HHP anchors would avoid the potential obstruction of the gravity block on the seabed and while the anchors would be easier to pick up and inspect than the gravity block they have to be reset when put back.

7.5 Screw Anchors

The seabed sediment at the mooring locations is well suited to the use of screw anchors. Screw anchors have been extensively used in the mussel farming and aquaculture industry and have application for the mooring of small craft. They are a particularly efficient way to anchor floating vessels and structures, they are lightweight in relation to the holding power or pull out resistance developed and do not require heavy marine plant for their installation. A standard screw anchor, as used on marine farms in the Marlborough Sounds, features the use of an 800 mm diameter steel auger/anchor plate at the end of a 6 m long, 50 mm diameter shaft. Such an anchor is excellent for resisting vertical pullout loads but the principal hydrodynamic forces exerted on moored vessels by waves and tidal currents are lateral or horizontal loads. In a Sounds type application the screw anchors resist lateral forces by bending above the anchor plate into approximate line with the applied load. Typically the anchors at one end of the farm take the tidal current force in one direction only. When the tide reverses the anchors at the opposite end of the farm take the drag force. The bending is a permanent or plastic deformation – indicated by slotting in the seabed – which is acceptable if the anchor is not subject to load reversals and the level of strain is limited. Load reversals are a constant of a wave environment, the anchors must be provided with a means of resisting lateral forces at the seabed otherwise the anchor shaft will snap off. The screw anchors can be designed to be fitted with passive earth pressure resisting plates which are forced into the seabed as the anchor is screwed in, they will be required if shafted screw anchors are used for mooring vessels.

A more recent development is the use of shaftless screw anchors. The screw anchor is screwed in using a shaft which is connected to the screw anchor and fitted over the top of the mooring warp or chain. The mooring warp runs up the inside of the installation shaft. Once the auger plate screw anchor has been set at the design depth the shaft is withdrawn by pulling it back over the mooring warp and recovering it to the surface.

7.6 Safety Factor

The safety factor is readily determined by dividing the available resistance by the maximum force. The minimum safety factor could be taken as 2 given that minor dragging in response to the peak force is not catastrophic. The values generally are in excess of 3 which is quite satisfactory, particularly since weak soil bottom conditions have been assumed.

8.0 MOORING LINE ANALYSIS

The mooring line transmits mooring forces acting on the vessel to the anchor. There are two aspects that are important, the strength of the line and its elasticity. The elasticity is either an inherent property of the line, rope, material itself or is a function of the weight of the line and the natural tendency of a suspended line to form a catenary shape.

An analysis of the mooring system using OCEL's catenary program and the maximum mooring forces determined by the analysis showed that the mooring systems given by the TDC specification are relatively stiff. At maximum load none of the chain remains on the seabed and an upward force is applied to the anchor. An analysis for the case of a QS force equal to 25 kN showed that the angle of the chain at the block was 20° to the horizontal. The upward force component on the anchor was 0.9 kN. This shortcoming from a mooring point of view, an upward force applied to the anchor, is an unavoidable consequence of the need to restrict the length of the mooring line and hence the radius of the swing circle. Provided that the anchor has sufficient weight or resistance to uplift to accommodate the upward component of the mooring line tension this is not a problem, it is just that the relative inelasticity of the mooring will result in increased shock loading or impact force. This can be reduced by incorporating a length of nylon line in the mooring line, using the nylon line to bypass a length of chain by arranging the bypassed length in a loop and connecting the nylon across the ends. Alternatively a proprietary Seaflex elastic unit could be used. These could be considered for moorings in exposed – to open sea – conditions.

The chain sizes used in the mooring system have a sufficient factor of safety for the intended purpose. For example the maximum QS load for a vessel up to 12 m long is 9.7 kN, the minimum chain diameter in the line is 16 mm diameter, and the factor of safety, minimum breaking load (MBL) divided by the QS load is 96/9.7 = 9.9. The minimum factor of safety could be taken as 5 to 6 for a rigging application, the larger factor achieved allows a margin for impact or TD loads and some wear, up to 10% loss of diameter. The factor of safety decreases from 9.9 to 8.0 for 10% loss of chain diameter. For larger vessels the line elements can be sized on the basis of a factor of safety equal to 10.

The prime concern with the existing moorings is the lack of elasticity in the mooring, the elasticity absorbs the TD load peaks without transmitting them to the anchor itself. The ground chain component of the mooring leg is a major contributor to catenary action elasticity because of its relative weight. The minimum length of ground chain has been set at 6 m for vessels longer than 6 m to make a significant contribution to the elasticity of the mooring.

9.0 CONCLUSIONS/PROPOSED REVISED SPECIFICATION

The existing TDC moorings appear to have performed well to the extent that OCEL is unaware of failures. The revision of the TDC mooring guidelines discussed in this report is part of an ongoing review to improve the moorings on the basis of experience. To that extent the Guidelines are a live document. The revision also aims to bring the guidelines in line with those of other regional authorities, in particular the NRC Guidelines, for consistency and in pursuit of a national best industry practice while recognising that mooring conditions vary from area to area.

The mooring categories have been simplified in line with the NRC Guidelines, avoiding fine distinctions between the lengths while ignoring the type of vessel moored. By broadening the mooring categories the moorings has become less specific and more flexible in accommodating different vessels should the ownership of the mooring change. The proposed classes and mooring element component sizes are given in Table No 1.

The principal reservations about the system relate to the relative inelasticity or stiffness of the system. This is of significance for the vessels in open roadsteads exposed to wave action. Some elasticity has been added to the system by increasing the length of the ground chain leg to the length of the vessel moored. The boat owners could also reduce the snatch loads on their vessels by incorporating a length of nylon in the mooring line, retaining the chain but bypassing it.

APPENDIX A

APPENDIX B

Swing Mooring Inspection Form

Mooring No ....

Please Print All Details

Mooring Owners Name...

Mooring Owners Address ....

Mooring Owners Phone No ....

Mooring Area ....

GPS Position ....

Inspection Date... Inspection Time...

Water Depth at Time of Inspection .... m

Details of Mooring

Type of Block... Description/Weight...

Ground Chain: Length .... Size...

Intermediate Chain: Length .... Size...

Headline: Length .... Size...

Floatline: Length .... Size...

Buoy Type .... Description/condition...

Swivel Diameter.. mm Swivel Location...

Headline Chafe Protection Type.................................... Condition...

Details of Vessel Using Mooring

Boat Name..

Type: Launch.................... Yacht.................... Other.......................................

Length...................................... m Beam .... m Draft.................................. m

Vessel Colour(s) ....

	Checked	Items Replaced	Specify/Comments
Block	☐	....	
Bottom Shackle	☐	....	

Bottom Chain ☐ ....

Av dia............mm min dia.................... mm ....

2nd Shackle ☐ ....

Middle Chain ☐ ....

Av dia............mm min dia.................... mm ....

3rd Shackle ☐ ....

Top Chain ☐ ....

Av dia............mm min dia.................... mm ....

Swivel ☐ ....

4th Shackle ☐ ....

Headline ☐ ....

Numbered Buoy ☐ ....

Diagram of Mooring

This is to certify that I have inspected and service this mooring, and the information noted above is true and correct.

Company ....

Name of Contractor ....

Signature of Contractor..

APPENDIX C

TASMAN DISTRICT COUNCIL - MOORING REVIEW 2013

VESSEL DESCRIPTION							
Length	≤6m	≤6m	≤12m	≤12m	≤18m	≤18m	>18m
Vessel type	Launch	Yacht	Launch	Yacht	Launch	Yacht	
Length for computation	6	6	12	12	18	18	**S**
Beam	2.8	2.8	4.4	4.4	5.4	5.4	**P**
Draft	1	1.5	1.4	2	2	2.5	**E**
Windage area on bow	5	4	11	6	22	11	**C**
Wind Force							**I**
Drag Coefficient Cd - AS3962	1.2	1.1	1.2	1.1	1.2	1.1	**F**
Wind speed m/sec 3 sec gust	45	45	45	45	45	45	**I**
Wind sustained 30 sec speed	36.7	36.7	36	36	36	36	**C**
Wind pressure kPa	0.81	0.81	0.81	0.81	0.81	0.81	
Wind Force kN	4.86	3.56	10.69	5.35	21.38	9.80	**D**
Current Force							**E**
Current speed knots	0.5	0.5	0.5	0.5	0.5	0.5	**S**
Hydrodynamic drag coefficient	0.15	0.15	0.15	0.15	0.15	0.15	**I**
Current pressure	0.010	0.010	0.010	0.010	0.010	0.010	**G**
Current Force kN	0.028	0.028	0.061	0.061	0.107	0.107	**N**
Wave Force							
Wave drift force kN	1.1	1.1	2.2	2.2	3.29	3.29	
TOTAL FORCE - Peak kN	5.99	4.69	12.95	7.61	24.78	13.20	
MAPUA CHANNEL							
Current speed - knots	6	6	6	6	6	6	
Hydrodynamic drag coefficient	0.15	0.15	0.15	0.15	0.15	0.15	
Current pressure	1.43	1.43	1.43	1.43	1.43	1.43	
Current Force kN	4.01	4.01	8.82	8.82	15.46	15.46	
TOTAL FORCE (Mapua) - Peak kN	9.97	8.67	21.71	16.37	40.14	28.55	
ANCHORS							
Weight in air - tonnes	1	1	2	2	4	4	
Submerged weight - tonnes	0.61	0.61	1.23	1.23	2.46	2.46	
Dimensions							
Width	1	1	1.5	1.5	1.85	1.85	
Depth	0.5	0.5	0.5	0.5	0.6	0.6	
Passive earth press. (kN) resist.							
Mud seabed cu = 10 kPa	10	10	15	15	22.2	22.2	
Friction/base shear resistance	10	10	22.5	22.5	34.225	34.225	
Total resistance	20	20	37.5	37.5	56.425	56.425	
50% burial	15	15	30	30	45.325	45.325	
Factor of safety - mud	2.51	3.20	2.32	3.94	1.83	3.43	
MAPUA							
Sand seabed/dense gravel $\phi = 50$							
Passive earth press. (kN) resist.	16.20	16.20	22.00	22.00	37.80	37.80	
Friction kN	6.00	6.00	12.30	12.30	24.60	24.60	
Total resistance	22.20	22.20	34.30	34.30	62.40	62.40	
Factor of safety - Mapua	2.23	2.56	1.58	2.10	1.55	2.19	