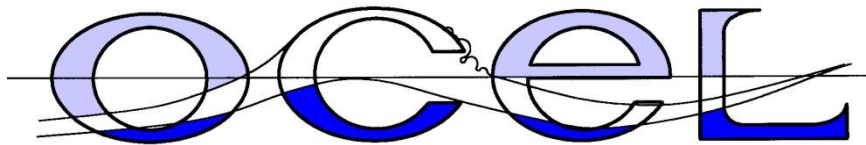


WAIKATO REGIONAL COUNCIL

SWING MOORING DESIGN REPORT



by



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1.0 INTRODUCTION

The Waikato Regional Council (WRC) and the Bay of Plenty Regional Council (BOPRC) have engaged OCEL Consultants NZ Limited (OCEL) to develop a swing mooring design formula for mooring areas in Waikato and the Bay of Plenty mooring areas (not including lakes). As part of the study brief the following elements are to be considered and addressed:

- categories for moorings areas to be developed
- mooring areas to be categorised – weather conditions (incl. windage) and sea bed to be considered
- vessel length considerations – with the following categories (metres)
 - 0 – 7
 - 7.1 – 9
 - 9.1 – 12
 - 12.1 – 15
 - 15.1 – 22
 - 22+ specifications to be confirmed by engineer or architect
- mooring elements to be described (and not excluded to) – anchor block weight, anchor ring diameter, mooring line length, ground chain, ground shackle, intermediate chain, intermediate shackle diameter, top rope, swivel, connecting elements eg welded rings, buoy rope
- anchor systems to be investigated – weight when submerged
- advice to be provided on whether there is justification to categorise by vessel type (ie yacht, launch, catamaran) – or displacement weight considerations
- inspection periods are currently specified under consent condition – WRC requires every 3 years.

OCEL is well placed to undertake this work, being aware of mooring specifications elsewhere in New Zealand, having developed mooring specifications for other regional councils (Environment Canterbury (ECan), Marlborough District Council (MDC), Tasman District Council (TDC) and the Nelson City Council (NCC)) and through having worked on mooring solutions for offshore developments and loading systems.

While there is currently no national or regional marine industry standard for moorings in New Zealand the design should be broadly compatible with other proven (through practical experience) specifications in New Zealand and the Northland Regional Council's (NRC) Mooring Guidelines. The latter document was developed in collaboration with the Auckland Council, WRC and mooring contractors to address the current 'vacuum' with regard to the lack of a national standard. The mooring designs need to 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. The methods of calculating both environmental forces acting on moored vessels and anchor resistance are well established but need to be tempered by practical experience at each mooring location given the general lack of detailed geotechnical and environmental data for each location.

2.0 MOORING AREAS

The mooring areas to be considered for both the WRC and the BOPRC category are as follows:

2.1 WRC Mooring areas

Flaxmill (Maramaratotara) Bay	C
Port Charles - Carey Bay	C
Port Charles - Jetty	C
Port Charles - Little Sandy Bay	C
Great Mercury Island	C
Matapaua Bay	C
Tairua Harbour - Paku	C

Tairua Harbour - Tairua	C
Whangamata	B
Whitianga	B
Coromandel Harbour - Oamaru Bay	A
Coromandel Harbour - Puhi Rare Bay	A
Coromandel Harbour - Takawhare Bay	A
Coromandel Harbour - Te Kouma	A
Coromandel Harbour - Wyuna & McGregor Bay	A
Whaingaroa (Raglan)	B
Kawhia Harbour - North of Wharf	B
Kawhia Harbour - South of Wharf	B
Kawhia Harbour - Opposite Wharf	B
Kawhia Harbour - Te Waitere	A
Kawhia Harbour - Te Maika	B
Whangapoua	B
Brophy's Beach	B
Cook's Beach	B
Purangi Estuary	B
Mokau River	B
Opito Bay	C
Kirita Bay – Coromandel	C
Howell Bay – Coromandel	C
Matariki Bay – Coromandel	

2.2 BOPRC Mooring Areas

Bowentown	B
Causeway	B
Omokoroa	B
Ongare Point	B
Ohiwa	B
Te Puna – Plummers Point	A
Pilot Bay Inner	B
Piolt Bay Outer	B
Tauranga Town Reach	B
Tanners Point	A
Whakatane	B
Waikareao	B

The mooring areas can be subdivided into three separate geographic categories distinguished by the nature of the environmental loads:

- **A** - Sheltered estuaries and inland water ways where the moored vessels are subject to environmental loads that are predominantly wind loads with minor contributions from tidal currents and waves. The waves will be short period wind generated waves on limited fetch distances, no ocean swell.
- **B** - Sheltered inlets or estuaries close to the estuary mouth, or main flow channel, where the moored vessels experience strong tidal currents. The environmental loads are predominantly wind and current loads with minor wave loads from locally generated short period waves.
- **C** - Sheltered open coast locations, wind force predominant, possible significant contribution from swell waves.

The category each mooring location has been assessed as falling into is shown by the letter after the location.

3.0 ENVIRONMENTAL DATA

To derive the environmental loads on moored vessels the following environmental data must be known for each mooring location:

- wind speed and direction
- tidal current velocities
- wave data for each mooring location.

The wind data can be derived from the New Zealand Standard AS/NZS 1170 Part 2 Wind Actions. New Zealand is divided into regions for which regional speeds are given. The WRC and BOPRC mooring areas are covered by regions A6 and A7. The wind data is derived for a 10 m height, 5 m height is more appropriate for moored vessels. The relationship between wind speed at the standard 10 m height and wind speed at 3 m is derived by an equation of the form

$$V_Z = V_{ZR} (Z/Z_R)^{.125}$$

Where Z is the height and Z_R is the reference height (10 m).

The tidal current data for the mooring locations given is not known for most of the locations nominated. However for the sheltered locations in estuaries and inlets away from the main channel, category A, the current speed can be conservatively taken at a maximum of .5 m/sec (1 knot) inclusive of the contribution from the wind driven surface current ($\approx 2\%$ of the wind speed). For mooring locations subject to strong tidal currents, in the main tidal channel or close to the estuary/inlet entrance, category B, the current speed is generally less than 2 m/sec (4 knots), 3 m/sec (6 knots) would be the upper limit. This could be exceeded for moorings in rivers prone to flooding.

4.0 GEOTECHNICAL

Detailed geotechnical information, soil strength parameters, for the seabed sediment – undrained shear strength for mud seabed, friction angle ϕ for sand - is generally not known for the mooring locations. In the absence of this information conservative assumptions can be made about the nature of the seabed.

In sheltered estuary type mooring locations, category A, the seabed is often soft cohesive, sandy silt or mud. The seabed can be characterised as soft cohesive sediment with an undrained shear strength, c_u , of 10 kPa.

Sand seabeds in strong current areas or open sea conditions are typically compact. The friction angle ϕ can be taken equal to 36° and the friction angle ($\tan \phi$) taken equal to 0.7. If the sand is loose the anchor block will typically work its way down into the seabed.

5.0 VESSEL CATEGORIES

Moored vessels are generally categorised as either power boats or yachts because the windage areas are greater for power boats or launches than yachts of equivalent length – reference AS/NZS 3962. Mooring locations are typically in sheltered locations away from strong currents (other than close to estuary entrances or main tidal channels) and rough seas and wind loads predominate. Mooring categories are established on the basis of the vessel's overall length (LOA), without differentiating within the mooring category between power boats and yachts. The mooring class classification is on length rather than vessel type, the latter generally only comes into consideration if the vessel concerned is slightly longer than the class length. If the vessel concerned is a yacht an 8.1 m long yacht could use a mooring designated for a vessel length ≤ 8 m because the governing load case for the mooring is an 8 m power boat which has a larger windage area than the equivalent length yacht.

Vessel displacement is a consideration in swell conditions. The wave length of swell waves (taken as waves with a period $T \geq 8$ seconds) is much greater than the vessel length so the vessel follows the swell wave profile as it passes. As the vessel slides down the face of a swell wave the size of the downslope force component to be

resisted by the mooring is directly related to the vessel weight or displacement. Moorings subject to swell conditions generally have to be made more elastic to increase the excursion distance and stop the mooring coming up hard.

The windage area for each vessel is specific to its design and intended use but typical windage areas for mooring design purposes are given by AS 3962 (Guidelines for Design of Marinas) for a range of vessel lengths and type – powerboats and yachts. The AS 3962 windage area figures bow into the weather/wind, given that the moored vessel can weathervane on its mooring, have been used for this report however they cover monohulls not catamarans. For powerboats with a catamaran design and length less than 12 m the beam of the power boat catamaran vessel is generally close to that of an equivalent length monohull, within the length/beam ratio of 3 - 4. For longer catamarans the length/beam ratio can reduce to 2 producing vessels such as the workboat 'Guru' shown in Photograph No 1. This vessel is 22 m long but has an 11 m beam. A swing mooring design for this vessel would have to be a one off specific design. While the WRC brief calls for specific design for vessels in excess of 22 m length the length limit for specific design is better set at 15 m. Beyond this length the normal length/beam ratios assumed in AS 3962 start to vary.



Photograph No 1

Catamaran yacht designs have a much wider beam than equivalent length monohulls because the heeling resistance is provided by the spread of the hulls not a keel however wind can flow between the hulls. The bow on windage area could be taken as equivalent to a power boat of the same length for power catamaran vessels up to 15 m length. Power boats don't have the same heeling resistance requirement generated by sail area.

6.0 METHODOLOGY

The first step in designing a mooring to safely hold the moored vessel is to know the total environmental force the mooring has to be designed to resist. The resultant force – the vector addition of wind, current and wave forces - acting on each vessel is compared with the ultimate resistance provided by the anchor to derive the safety factor. 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.

7.0 ENVIRONMENTAL FORCES

The total environmental force has three components - wind load, current load and wave load. Each environmental load will be considered separately in the following.

7.1 Wind Load

The design wind speeds used for the calculation of the wind loads were taken from the New Zealand Standard AS/NZS 1170 Part 2 Wind Actions. AS/NZS 1170 gives the regional 3 second wind gust speeds for regions in New Zealand. The WRC locations are covered by regions A6 and A7. The BOPRC locations are covered by region A7. To derive the wind speed V_{des} for each location in accordance with AS/NZS 1170 the regional wind speed is multiplied by a number of site specific parameters, $V_{des} = M_z \cdot M_{z,cat} \cdot M_s \cdot M_t \cdot V_R$:

M_z	=	wind directional multiplier (≤ 1)
$M_{z,cat}$	=	terrain/height multiplier (1 or this application)
M_s	=	shielding multiplier (no shielding, taken as 1)
M_t	=	topographic multiplier (taken as 1)
V_R	=	regional wind speed

The value of the modification parameters has been taken equal to 1 giving the design velocity V_{des} equal to the regional wind speed. The 3 second wind gust speeds, V_R (where R is the return period) used are $V_{50} = 39$ m/sec.

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 can be adjusted to give the sustained wind over a longer period, taken as 30 seconds, using a logarithmic relationship of the form:

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

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 for the particular location.

An accurate value for the A constant is generally available only for a limited number of specific locations. In the absence of a local figure for all the mooring locations the relationship between the 50 year extreme 3 second wind gust and a number of different averaging times has been taken from the UK HSE document, Table 2.4 reproduced as Table No 1 in this document. The 30 second wind gust speed is of interest for the mooring application. Extrapolating from Table No 1 for a regional - A6 & A7 - 3 second wind gust speed of $V_R = 39$ m/sec the design 30 second gust wind speed is 35 m/sec. This is the wind speed at 10 m, reducing this to the wind speed at 5 m height gives 32 m/sec.

Extreme wind speed (m/sec) with an averaging time of:										
(Hour)	(Minutes)					(Seconds)				
1	15	10	5	2	1	30	15	10	5	3
30	31	31	32	34	35	37	38	39	40	41
31	32	32	33	35	36	38	40	41	42	43
32	33	33	34	36	37	39	41	42	43	44
33	34	34	35	37	39	41	43	43	45	46
34	35	35	36	38	40	42	44	45	46	47
35	36	36	38	40	41	43	45	46	48	49
36	37	38	39	41	42	45	47	48	49	50
37	38	39	40	42	44	46	48	49	51	52
38	39	40	41	43	45	47	50	51	52	53
39	40	41	42	44	46	49	51	52	54	55
40	41	42	43	45	47	50	53	54	55	56
41	41	43	44	47	49	52	54	55	57	58
42	43	44	45	48	50	53	55	57	58	60

Table No 1
Extreme wind speeds for different averaging times (UK, HSE, 1995)

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 q , was calculated in accordance with AS/NZS 1170, the same method as used for AS 3962, the Australian Code - Guidelines for the Design of Marinas,

$$q = .5 \cdot \rho_{\text{air}} \cdot V_{\text{des}}^2 = .0006 \cdot V_{\text{des}}^2 \text{ (kPa)}$$

where ρ_{air} is the density of air = 1.225 kg/m³ for dry air at 15°C.. The wind force F_{Dw} on the moored vessel is

$$F_D = C_D \cdot A \cdot q$$

where C_D is the drag coefficient and A is the windage area, the projected area of the vessel normal to the wind direction. The typical windage areas for nominated vessel lengths are given by the AS 3962 code. The windage areas are different for launches and yachts being higher for launches. Drag coefficient values are also given by the AS 3962 code.

7.2 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 F_{Dc} acting on each vessel is calculated using a form drag equation taken from AS 3962.

$$F_{Dc} = p \cdot A$$

Where the pressure $p = K \cdot v^2$ and A is the submerged area transverse to the flow. K is a constant, equal to 0.15 for vessels bow on to the current and 0.2 for vessels beam on to the current (hulls, $K = 0.6$ for keels). The tidal currents vary for each mooring location. A minimum value of 0.5 m/sec was taken for estuary locations away from the main channel and the estuary entrance.

A wind driven surface current approximately equal to 2% of the wind speed was added to the tidal current to derive a total current.

7.3 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 as an order of magnitude load 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 WRC mooring locations vary from sheltered to open sea conditions however the open sea conditions are either in the Firth of Thames or in bays on the east side of the Coromandel peninsula. While they have some exposure to swell the conditions are not potentially as severe as elsewhere in New Zealand. In any event it is unlikely to be direct exposure to open sea swell waves but swell waves modified by the processes of refraction and diffraction. The waves to which the moored vessels will be directly exposed 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 loads rather than sustained loads.

7.4 Total Environmental Force

The constituent QS forces acting on each vessel length category are presented in spread sheet form attached as Appendix A for categories A and B. The force on the category C mooring is close to that for category A provided sufficient elasticity has been incorporated in the mooring. The loads imposed by wave loads are less QS loads than sharp snatching loads.

The total force is given as the sum of the constituent forces. The concurrent wind force is maintained the same for all the WRC and BOPRC 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 however for the category B locations the tidal current force can attain a significant magnitude.

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 generally above the minimum value of 2.

8.0 RESISTANCE AND SAFETY FACTORS

The anchor resistance capacity, based on the use of nominated concrete weight blocks 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 generally satisfactory, being ≥ 2 , for the mooring location areas categories A and C 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 - in the exception of the category B areas the current induced force becomes significant. 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 category B locations are lower because of the increased current drag but are based on the assumption of relatively low soil strengths. Soft marine mud and loose sand size material is not stable in currents of up to 6 knots, the bottom has to be either hard cohesive material or non cohesive material of sufficient size and density/compactness to be stable in the flow. Some site specific geotechnical investigation work is necessary in the high current areas to determine the actual nature of the seabed. The anchor blocks also have to be set into the seabed. Practical experience of what works in these locations is important in the absence of detailed geotechnical information. 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. This contradiction can only be resolved by a detailed investigation of the bottom sediment in the category B areas to determine their actual properties.

9.0 ANCHOR RESISTANCE – CONCRETE BLOCK GRAVITY ANCHORS

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 familiar with the seabed conditions within the mooring areas designated by the WRC and the BOPRC and has had to assume soil strength characteristics. The anchor resistance figures derived in the spreadsheets are conservatively based on soft marine mud, undrained shear strength equal to 10 kPa, and compact sand $\phi = 36^\circ$.

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 WRC and BOPRC 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.

10.0 ANCHORS

10.1 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.

10.2 Gravity Anchors

Concrete block 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 and being concrete minimise corrosion effects. 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 a large 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 compact sand is approximately .7.

For a 2,000 kg concrete weight, shown in Photograph No 2, the submerged weight is 1,146 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 (2,000 kg) is embedded in even a soft silt seabed, undrained cohesive strength taken at $c_u = 10$ 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 1, 2 and 4 tonne air weight anchors included in Appendix B.

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. Two 2 tonne blocks connected by a bridle offer higher resistance than one 4 tonne block on account of the higher surface area and passive earth pressure resistance available but are harder both to install and lift for periodic inspection.

The cost of a 2 tonne concrete block anchor is in the region of \$1,500 (plus GST). Installation costs will vary widely depending on the remoteness of the location and the availability of suitable marine plant.



Photograph No 2

10.2 Alternative Anchor Systems

While gravity block anchors have generally been employed for all mooring locations in New Zealand been employed there are alternative anchor systems available, some of which will be considered here.

10.2.1 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.

10.2.2 Screw Anchors

The seabed sediment at the mooring locations is generally 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. They do not require to be 'set' or dragged to develop their full anchoring potential and they

can develop close to full pullout capacity immediately after installation in the as installed position. Installation accuracy is also excellent. They are screwed in vertically and a DGPS (Differential Global Positioning System) sensor can be installed coaxial with the suspension line lowering the installation tool on the workboat A-frame to give the as installed position with accuracy of the order of ± 0.5 m. Unlike conventional anchors screw anchors can accommodate high vertical loads at the anchor position, chain is not required to ensure that the mooring load applied to the anchor is horizontal. Screw anchors also have the least environmental impact on the seabed.

The installation cost, inclusive of material cost, for a typical screw anchor is of the order of \$1,800.00 for a marine farm where there is typically a large number of anchors to be installed and mobilisation costs can be spread over all the anchors. Mobilisation costs are prohibitive for one mooring, a number have to be done at the same time.

The anchor plate size and the seabed soil strength determines the pullout capacity. While each anchor requires specific design knowing the nature of the seabed and the mooring force needed, the design effort required is minor once the information is available.

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. This type of anchor is shown in Figure No 1.

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. These anchors can be used with a conventional concrete block as shown in Figure No 2. The concrete weight resists lateral loads the screw anchor resists vertical loads and ultimately lateral loads if the concrete block drags.

The length of the mooring and hence the swing room can be much reduced if an elastic mooring element, SEAFLEX or MARINEFLEX is used in the mooring line assembly. Essentially the elastic element is a form of marine bungy cord made of rubber strand elements. The angle of the mooring line is much steeper than a conventional mooring and the resulting uplift on a conventional concrete block mooring would make it unstable. The uplift resistance of the screw anchor can be checked immediately after installation – commonly done on offshore aquaculture mooring applications – so detailed geotechnical investigation is not generally required.

11.0 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.

The typical mooring has three components:

- Bottom chain, connected, as the name suggests, at the bottom of the mooring leg to the anchor block
- Intermediate chain, the next lighter chain element connected to the top of the bottom chain
- Top rope, connecting from the top of the intermediate chain to the mooring buoy.

The size of the mooring component elements is closely similar across New Zealand regional specifications. The suggested mooring specifications for the WRC and BOPRC mooring areas are shown in Table No 2. The principal difference from equivalent specifications is the use of a longer ground chain than normal in an effort to increase the 'elasticity' of the moorings.

A swivel is required in the mooring leg assembly to avoid winding up the chain. The swivel (one) to be located in open/mid water at the top of the intermediate chain and to be submerged at all times. An anode should be located on the intermediate chain near the top.

A 7 m minimum length of ground chain is used to increase the elasticity of the mooring. A shorter length of heavier chain than specified, say 5 m, could be used to reduce swing room. The weight of the chain lengths to be the same.

The maximum acceptable wear on any component is 10% loss of diameter.

MOORING SPECIFICATION

Vessel	A	B	C	D	E	F	G	H
Length	Mooring Block Weight (air)	Shackle	Ground Chain	Shackle or Ring	Intermediate Chain	Swivel	Top Chain or Rope	Buoy Rope
≤ 7 m	1 tonne	32 mm	7 m long 32 mm	22 mm	16 mm 1.5 x depth at high water	22 mm SWL 5 tonne	Min 2.5 m 12 mm chain 20-24 mm rope	Min 12 mm
7.1-9 m	2 tonne	32 mm	7 m 32 mm	22 mm	20 mm 1.5 x depth at high water	22 mm SWL 5 tonne	Min 2.5 m 16 mm (galv) chain 24-32 mm rope	Min 12 mm
9.1-12 m	2 tonne	38 mm	7 m 38 mm	25 mm	20 mm 1.5 x depth at high water	25 mm SWL 7 tonne	Min 2.5 16 mm (galv) chain 24-32 mm rope	Min 12 mm
12-1-15	4 tonne	38 mm	7 m 38 mm	28 mm	24 mm 1.5 x depth at high water	28 mm SWL 7 tonne	16 mm chain (galv) 32 mm rope	Min 12 mm
> 15 m	Specified design							

Table No 2

Alphabetic Referenced A-H shown in Figure No 3.

An analysis of the mooring system for a 12 m long yacht using OCEL's catenary program and the maximum mooring forces determined by the analysis showed that the mooring systems given by the WRC and BOPRC specifications are relatively stiff. This relative stiffness is the same for all the swing mooring specifications. At maximum load none of the chain remains on the seabed and an upward force is applied to the anchor. The analysis for the 12 m yacht in 6 m of water subject to a QS force equal to 8.4 kN showed that the angle of chain at the block for a 5 m length of ground chain is 18.6°. This corresponds to an uplift of 2.75 kN on the anchor. If the ground chain length is increased to 7 m the uplift angle reduces to 12.8° and the uplift force is 1.84 kN. An analysis for the case of a 12 m yacht subject to a QS force equal to 8.3 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 as shown in Figure No 4. Alternatively a proprietary SEAFLEX or MARINEFLEX 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.

12.0 CONCLUSION

The WRC and BOPRC mooring specifications cover a wide range and geographic spread of mooring locations. This report establishes a methodology and a spreadsheet format, incorporating swing mooring design formula, to enable the mooring loads to be established for different vessels, based on mooring categories determined by the length of the vessel, and the appropriate anchoring system to be defined.

The spreadsheets are not entirely prescriptive because of the lack of geotechnical and environmental data for each location and the conclusions have to be tempered by practical operating experience in each of the mooring areas considered. The geotechnical information assumed for the anchor resistance calculations, assumed on the basis of OCEL experience is however conservative so the resistance calculated should be generally be the lower bound to the actual resistance available. If the soil resistance is less than assumed the anchor should sink in deeper than assumed and develop greater resistance. The anchor block sizes considered are also becoming standard in most mooring areas in New Zealand and have generally worked well if properly embedded in the seabed to generate passive earth pressure resistance which is an important component of the total resistance. The seabed in the high current areas should be subject to specific geotechnical investigation work to determine the actual properties of the seabed. To resist the high current loads with a factor of safety in excess of 2 the seabed sediment should be stronger than assumed. Practical operating experience is of particular interest in these areas.

APPENDIX A

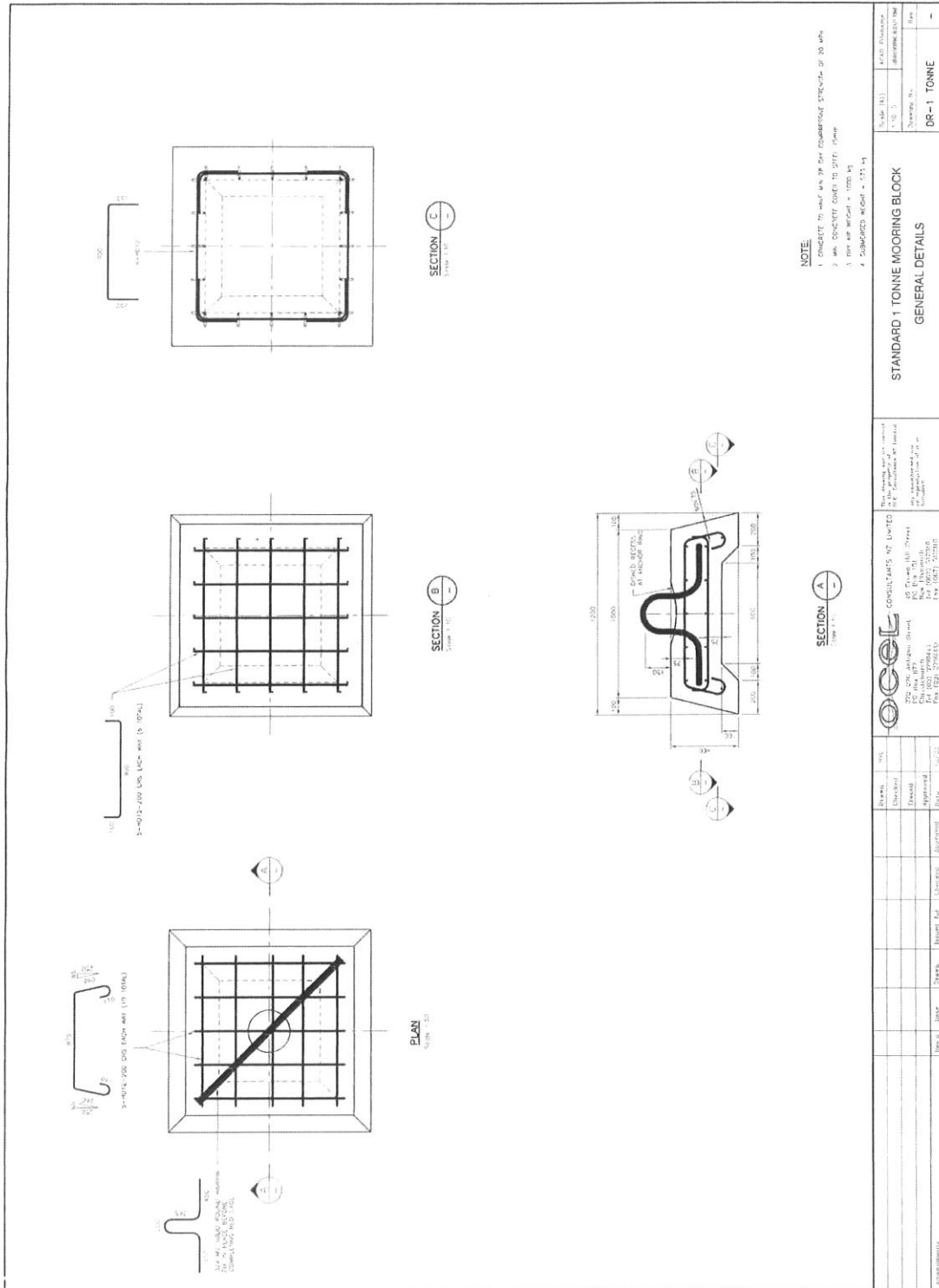
WAIKATO REGIONAL COUNCIL & BOPRC - MOORING DESIGN 2015												
CATEGORY A												
VESSEL DESCRIPTION												
Length	≤7m	≤7m	7.1-9m	7.1-9m	9.1-12m	9.1-12m	12.1-15m	12.1-15m	15.1-22m	15.1-22m	>22m	>22m
Vessel type	Launch	Yacht	Launch	Yacht	Launch	Yacht	Launch	Yacht	Launch	Yacht	Yacht	Launch
Length for computation	7	7	9	9	12	12	15	15	22	22	Actual	Actual
Beam	3.1	2.5	3.7	3.1	4.4	4	5	4.6	5.9	5.3		
Draft	1	1.5	1.3	2.1	1.4	2.4	1.5	2.5	2.5	3	S	S
Windage area on bow	4	3	6	5	11	6	18	9	26	13	P	P
Wind Force												
Drag Coefficient Cd - AS3962	1.2	1.1	1.2	1.1	1.2	1.1	1.2	1.1	1.2	1.1	C	C
Wind speed m/sec 3 sec gust at 10m	39	39	39	39	39	39	39	39	39	39	I	I
Wind sustained 30 sec speed at 5m	32	32	32	32	32	32	32	32	32	32	F	F
Wind pressure kPa	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	I	I
Wind Force kN	2.95	2.03	4.42	3.38	8.11	4.06	13.27	6.08	19.17	8.79	C	C
Current Force												
Current speed m/sec	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	D	D
Hydrodynamic drag coefficient	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	E	E
Current pressure	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	0.038	S	S
Current Force kN	0.105	0.070	0.162	0.122	0.208	0.180	0.253	0.216	0.498	0.298	I	I
Wave Force												
Wave drift force kN	0.05	0.05	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	N	N
TOTAL FORCE - Peak kN	3.10	2.15	4.69	3.60	8.52	4.44	13.82	6.60	20.07	9.48		
ANCHORS												
Weight in air - tonnes	1	1	2	2	2	2	4	4	4	4		
Submerged weight - tonnes	0.6	0.6	1.1	1.1	1.1	1.1	2.3	2.3	2.3	2.3		
Dimensions												
Width	1	1	1.4	1.4	1.4	1.4	1.7	1.7	1.7	1.70		
Depth	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6		
Passive earth press. (kN) resist.												
Mud seabed cu = 10 kPa												
Mud seabed passive resistance	10	10	14	14	14	14	20.4	20.4	20.4	20.4		
Friction/base shear resistance	10	10	19.6	19.6	19.6	19.6	28.9	28.9	28.9	28.9		
Total resistance	20	20	33.6	33.6	33.6	33.6	49.3	49.3	49.3	49.3		
Factor of safety - mud	6.44	9.31	7.17	9.33	3.94	7.58	3.57	7.47	2.46	5.20		
Sand Seabed												
Sand seabed compact $\phi = 36^\circ$												
Passive earth press. (kN) resist.	4.33	4.33	6.06	6.06	6.06	6.06	10.60	10.60	10.60	10.60		
Friction kN - anchor sub x μ	4.01	4.01	8.02	8.02	8.02	8.02	16.04	16.04	16.04	16.04		
Side friction	1.58	1.58	2.21	2.21	2.21	2.21	3.86	3.86	3.86	3.86		
Total resistance	9.92	9.92	16.29	16.29	16.29	16.29	30.50	30.50	30.50	30.50		
Factor of safety - Sand	3.20	4.62	3.48	4.52	1.91	3.67	2.21	4.62	1.52	3.22		

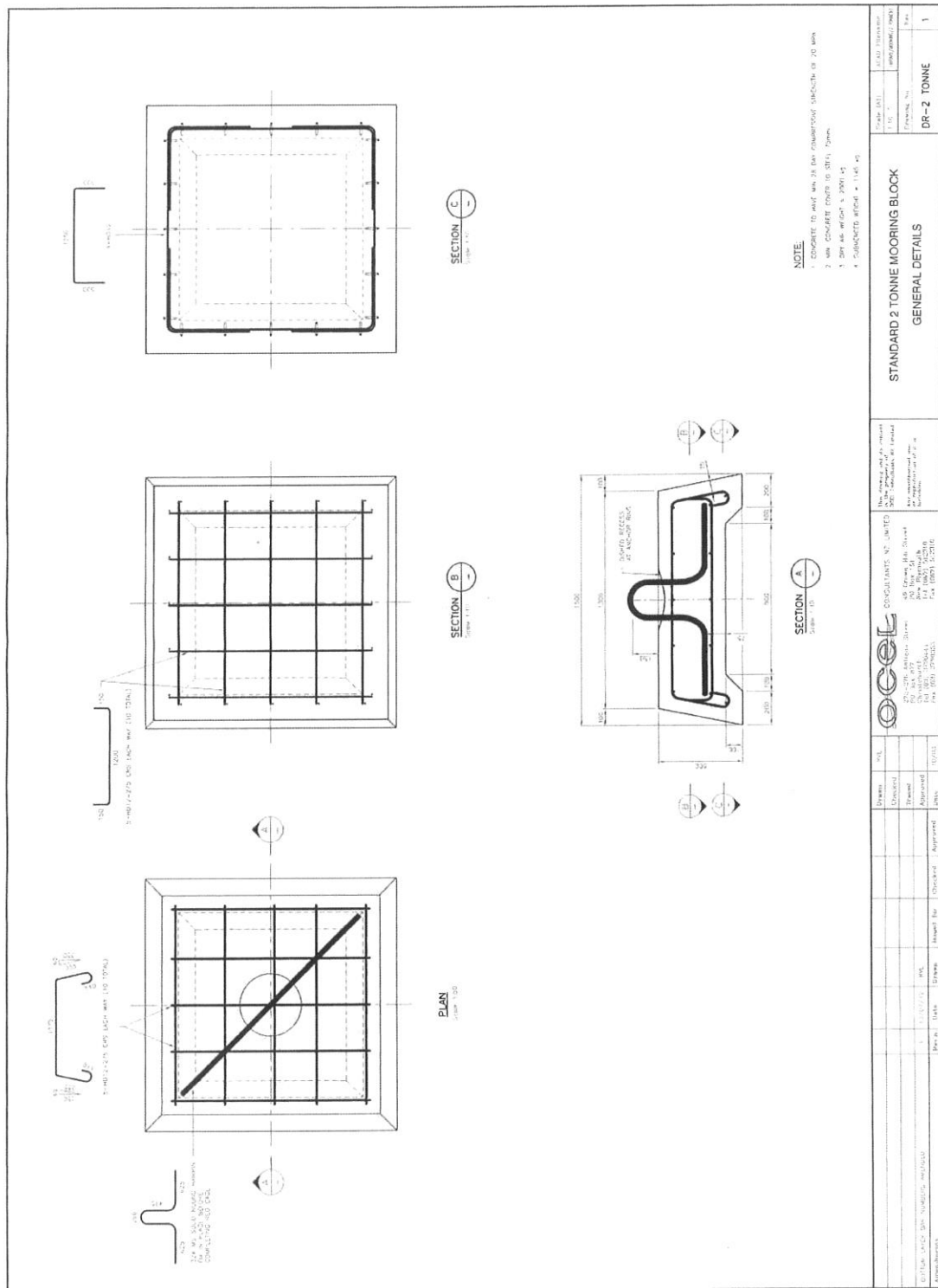
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CATEGORY B

VESSEL DESCRIPTION												
Length	≤7m	≤7m	7.1-9m	7.1-9m	9.1-12m	9.1-12m	12.1-15m	12.1-15m	15.1-22m	15.1-22m	>22m	>22m
Vessel type	Launch	Yacht	Launch	Yacht	Launch	Yacht	Launch	Yacht	Launch	Yacht	Yacht	Launch
Length for computation	7	7	9	9	12	12	15	15	22	22	Actual	Actual
Beam	3.1	2.5	3.7	3.1	4.4	4	5	4.6	5.9	5.3		
Draft	1	1.5	1.3	2.1	1.4	2.4	1.5	2.5	2.5	3	S	S
Windage area on bow	4	3	6	5	11	6	18	9	26	13	P	P
Wind Force												
Drag Coefficient Cd - AS3962	1.2	1.1	1.2	1.1	1.2	1.1	1.2	1.1	1.2	1.1	C	C
Wind speed m/sec 3 sec gust at 10m	39	39	39	39	39	39	39	39	39	39	I	I
Wind sustained 30 sec speed at 5m	32	32	32	32	32	32	32	32	32	32	F	F
Wind pressure kPa	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	I	I
Wind Force kN	2.95	2.03	4.42	3.38	8.11	4.06	13.27	6.08	19.17	8.79	C	C
Current Force												
Current speed m/sec	2	2	2	2	2	2	2	2	2	2	D	D
Hydrodynamic drag coefficient	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	E	E
Current pressure	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	0.600	S	S
Current Force kN	1.674	1.125	2.597	1.953	3.326	2.880	4.050	3.450	7.965	4.770	I	I
Wave Force												
Wave drift force kN	0.05	0.05	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	G	G
TOTAL FORCE - Peak kN	4.67	3.20	7.12	5.43	11.64	7.14	17.62	9.83	27.53	13.96	N	N
ANCHORS												
Weight in air - tonnes	1	1	2	2	2	2	4	4	4	4		
Submerged weight - tonnes	0.6	0.6	1.1	1.1	1.1	1.1	2.3	2.3	2.3	2.3		
Dimensions												
Width	1	1	1.4	1.4	1.4	1.4	1.7	1.7	1.7	1.70		
Depth	0.5	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6		
Passive earth press. (kN) resist.												
Mud seabed cu = 10 kPa												
Mud seabed passive resistance	10	10	14	14	14	14	20.4	20.4	20.4	20.4		
Friction/base shear resistance	10	10	19.6	19.6	19.6	19.6	28.9	28.9	28.9	28.9		
Total resistance	20	20	33.6	33.6	33.6	33.6	49.3	49.3	49.3	49.3		
Factor of safety - mud	4.28	6.25	4.72	6.19	2.89	4.71	2.80	5.01	1.79	3.53		
Sand Seabed												
Sand seabed compact $\phi = 36^\circ$												
Passive earth press. (kN) resist.	4.33	4.33	6.06	6.06	6.06	6.06	10.60	10.60	10.60	10.60		
Friction kN - anchor sub x μ	4.01	4.01	8.02	8.02	8.02	8.02	16.04	16.04	16.04	16.04		
Side friction	1.58	1.58	2.21	2.21	2.21	2.21	3.86	3.86	3.86	3.86		
Total resistance	9.92	9.92	16.29	16.29	16.29	16.29	30.50	30.50	30.50	30.50		
Factor of safety - Sand	2.12	3.10	2.29	3.00	1.40	2.28	1.73	3.10	1.11	2.19		

APPENDIX B





APPENDIX C

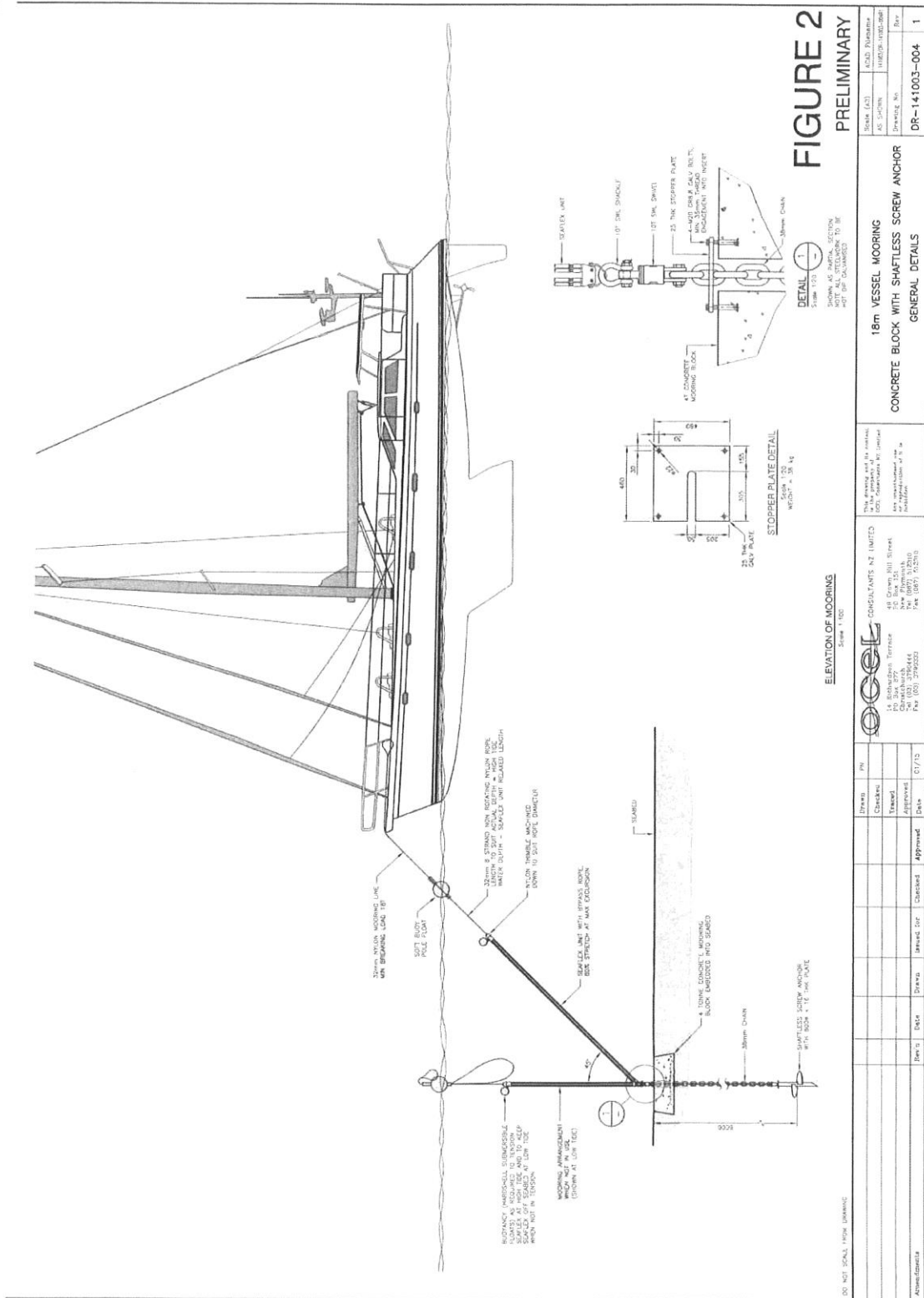


Figure No 2

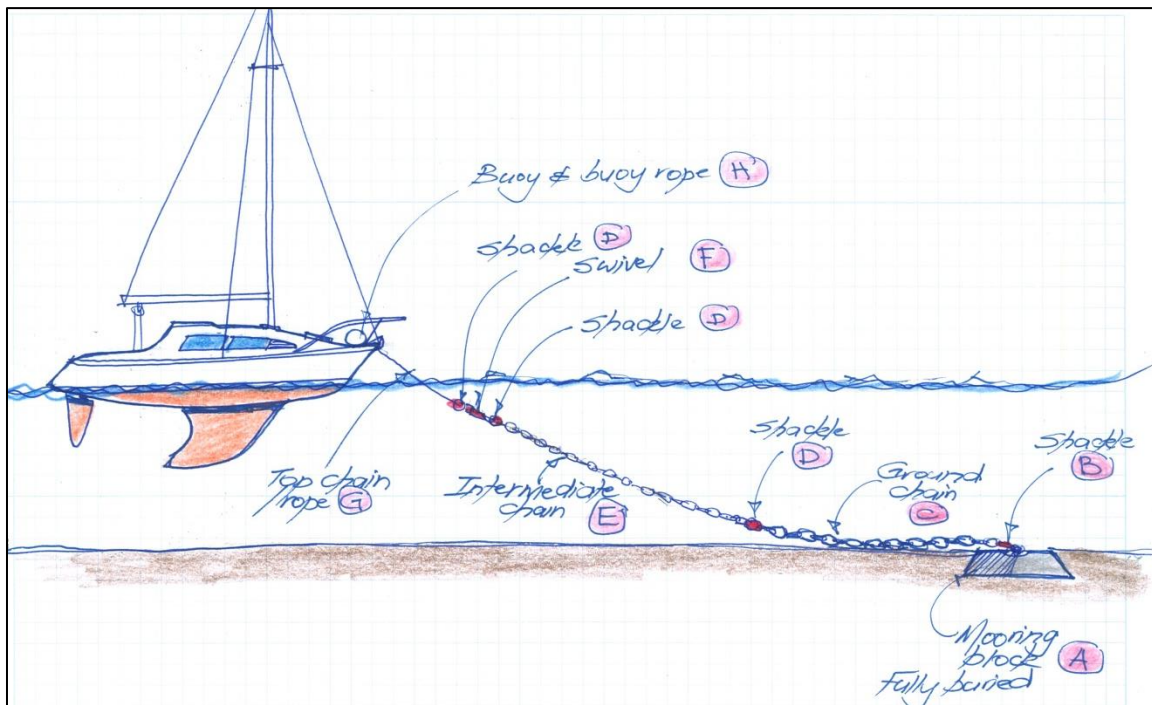


Figure No 3

