

Project Application

Volume 8



Inner West Marina

Parramatta River, Sydney

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Inner West Marina SYDNEY



Kendall Bay, Parramatta River
Sydney Harbour NSW Australia

MARINA BERTH

DEMAND ASSESSMENT



**Australian Marina
Management Pty Ltd**
marina consultants

Prepared for:
TLB Engineers Pty Limited
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1 Introduction

Engineering and planning consultants, TLB Engineers Pty Limited has been commissioned by Breakfast Point Pty Limited to undertake various tasks and studies in connection with proposals to develop a modern floating marina with associated facilities at Kendall Bay, on the Parramatta River in the NSW Local Government Area of Canada Bay in Sydney's inner west. Parramatta River is a part of Sydney Harbour, west of Sydney Harbour Bridge.

The proposed marina adjoins the waterside residential estate of Breakfast Point.

To be known as Inner West Marina Sydney, the facility has been designed to provide modern on-water floating berth storage for 172 vessels including five (5) berths to be reserved for day visitation by the general boating community who may seek to use the marina's facilities and services on a casual or short-term basis.

Whilst vessels to be berthed in the marina will range, in length, from less than 8 metres up to a maximum of 25 metres, it is anticipated that the majority of vessels berthing at Inner West Marina will range from 10 metres to 16 metres in length. This is similar to most other commercial marinas in NSW. The berth size mix for the proposed 172 berths at Inner West Marina is shown on the Marina Layout Plan (0103-DA03-E) attached at Appendix 1 of this study.

The marina has been designed to offer safe and secure berths and includes structured access for community members with disabilities and for those participating in Sailability activities.

It will provide boat owners with a sewage and waste water pump-out facility. There will be no provision for fuelling of vessels, nor for slipping or boat-lift facilities to remove boats from the water. All major repairs and maintenance to vessels will be required to be done at other service facilities some of which are nearby at Mortlake and Putney.

In addition to the 172 floating marina berths, at the location of the site's former industrial coal loading wharf, it is proposed to construct a new wharf, or jetty, with a kiosk at its outer or seaward end. A small building for marina management, with some amenities for marina patrons, is proposed to be located at the shore end of this new wharf.

Car parking for marina patrons is proposed to be provided in a dedicated area west of existing residential foreshore buildings.

Inner West Marina Sydney is planned to be operated as a commercial marina with berths made available to the wider community and not as a residential marina where berths are generally restricted to use by residents of dwellings within the residential estate.

1. Introduction (Continued)

In the western areas of Sydney Harbour and the Parramatta River, over the last 15 or so years, many waterfront industrial sites have been converted to residential properties. Some of these properties were re-developed with non-commercial marinas in which the use of berths was restricted to owners of residences within the properties. Some of these residential marinas remain highly under-utilised at a time when the wider community demand for on-water boat storage at commercial marinas far exceeds the available supply of berths.

Amongst the tasks, for which TLB Engineers Pty Limited has been engaged, is to identify both current demand and anticipated future demand for marina berthing at the proposed Inner West Marina Sydney.

TLB Engineers Pty Limited has therefore commissioned Australian Marina Management Pty Limited to provide an assessment of existing and anticipated future demand for marina berths in NSW and in Sydney in order to demonstrate demand for marina berths at the proposed Inner West Marina.

TLB Engineers has also requested Australian Marina Management Pty Limited to comment upon the proposed berth size distribution as well as the profile of vessels which are most likely to make up the demand for berthing at Inner West Marina Sydney.

2. Overview of Sydney Harbour On-Water Boat Storage

Sydney Harbour has an array of attractive waterways which, since the early 1800's, have provided a suitable venue for a wide range of community recreational boating activities including cruising, sailing, fishing, rowing and canoeing.

With its many tributaries, coves and bays, small boatsheds with moorings were established in the 1950s to moor and service those vessels requiring on-water storage. In addition to these boatshed “marinas”, to meet increasing demand for on-water boat storage, the NSW Government developed a system of private mooring licences which still exists today.

Further high demand for on-water boat storage in Sydney Harbour saw the licencing of private jetties to owners of waterfront properties and the leasing (or licencing) of waterway sites for purpose-built marinas such as commercial marinas, yachting, sailing and boating club marinas and more recently private residential marinas.

In addition to demand for on-water boat storage by the Sydney community, with its immediate access to the Tasman Sea and Pacific Ocean, Sydney Harbour is an attractive destination for visiting boat owners from regional NSW, other States and overseas. Sydney Harbour is also the backdrop to many major events such as the internationally renowned Sydney to Hobart yacht race classic, the New Year’s Eve fireworks displays, and the Sydney Ferry Race as part of the Sydney Festival. All of these and many other events add to the demand for on-water mooring and berthing of vessels in Sydney Harbour.

The following Table A is a summary extracted from the *Sydney Harbour Boat Storage Survey – June 2009*. It shows the total marina berths in Sydney Harbour at 30th June 2009 as well as commercial moorings associated with the facilities surveyed. The Summary is divided into west and east Sydney Harbour using Sydney Harbour Bridge as the dividing point.

TABLE A

SUMMARY OF SYDNEY HARBOUR MARINAS & BOATSHEDS

| TYPE OF FACILITY | WEST OF SYD HARBOUR BDGE | | | EAST OF SYD HARBOUR BDGE | | | TOTAL SYDNEY HARBOUR | | |
|---------------------|--------------------------|--------------|------------|--------------------------|--------------|------------|----------------------|--------------|--------------|
| | FACILITIES | BERTHS | MOOR'S | FACILITIES | BERTHS | MOOR'S | FACILITIES | BERTHS | MOOR'S |
| COMMERCIAL MARINAS | 12 | 584 | 176 | 14 | 574 | 602 | 26 | 1,158 | 778 |
| CLUB MARINAS | 1 | 0 | 6 | 4 | 396 | 105 | 5 | 396 | 111 |
| RESIDENTIAL MARINAS | 11 | 371 | 0 | 3 | 89 | 0 | 14 | 460 | 0 |
| COMMERC'L BOATSHEDS | 10 | 64 | 99 | 7 | 40 | 209 | 17 | 104 | 308 |
| CHARTER VESSELS | 4 | 54 | 0 | 2 | 14 | 0 | 6 | 68 | 0 |
| TOTALS | 38 | 1,073 | 281 | 30 | 1,113 | 916 | 68 | 2,186 | 1,197 |
| | | | | | | | | | |

Source: Sydney Harbour Boat Storage Survey – June 2009 – Australian Marina Management Pty Ltd

2. Overview of Sydney Harbour On-Water Boat Storage (Continued)

It can be noted from the above Table that the total of the west Sydney marina berths (1,073) is similar to the total of the east Sydney marina berths (1,113).

Included in the 1,073 berths in the west Sydney facilities however, it is noted that there are eleven (11) residential marinas with a total of 371 marina berths which are private berths not available to the wider community. There are also 54 charter vessel berths which are not in commercial marina facilities and are thus also not available to the wider community.

Available in west Sydney marinas, for use by the wider community, are therefore only 648 berths. It is also noted that the 371 private residential berths represent 36.4% of the total berths (1,019) available in the west Sydney area.

The details of the Sydney Harbour Boat Storage Survey – June 2009 are set out in the following appendices to this study as follows:-

- Appendix 2 – Commercial Marinas
- Appendix 3 – Club Marinas
- Appendix 4 – Residential/Private Marinas
- Appendix 5 – Commercial Boatsheds
- Appendix 6 – Charter Vessel Berthing

The 26 commercial marina facilities in Sydney Harbour have an average of only 45 berths per facility. As Appendix 2 will show however, without the two d’Albora Marinas, Rushcutters Bay (95 berths) and The Spit (135 berths), the remaining 12 east Sydney marinas have an average of only 29 berths. Without Birkenhead Point Marina (187 berths) and d’Albora Marina Cabarita (124 berths) the remaining 10 west Sydney marinas have a similar average of only 27 berths.

These marinas are extremely small by interstate and international standards. Without having additional commercial swing moorings, vessel repair and hard-stand facilities, and land based retail outlets, the feasibility of some of these marinas would likely be doubtful.

Appendix 3 will show that whilst there is one sailing club in the west Sydney area surveyed there are no club marina berths available.

Appendix 4 shows the berths at residential and private marinas. Reference has been made earlier to the extent of the private residential berths in the west Sydney area. Further comments about the vessel occupancy levels at these residential marinas will be made later in this study.

2. Overview of Sydney Harbour On-Water Boat Storage (Continued)

Appendix 5 shows the Commercial Boatsheds in Sydney Harbour. These offer small numbers of marina berths and have a heavy reliance on their commercial swing moorings.

The charter vessel berthing in Sydney Harbour is shown at Appendix 6 and is usually fully occupied with commercial charter vessels with no availability of berths for the wider community.

The following Table B is a summary extracted from the *Survey of NSW Maritime Authority Private Moorings – June 2009*. It shows the total private swing mooring licences existing in Sydney Harbour at 30th June 2009.

TABLE B

| <u>NSW MARITIME - PRIVATE MOORINGS - SYDNEY HARBOUR</u> | | |
|--|---------------------------------|-----------------------------|
| <u>JUNE 2009</u> | | |
| <u>Moorings Areas</u> | <u>Moorings Licences</u> | <u>Waiting Lists</u> |
| Sydney Harbour (Area A) | 1,008 | 582 |
| Sydney Harbour (Area B) | 1,000 | 177 |
| Sydney Harbour (Area C) | 1,023 | 29 |
| Sydney Harbour (Area D) | 933 | 183 |
| Sydney Harbour (Area E) | 887 | 231 |
| <u>Total Private Moorings Sydney Harbour</u> | <u>4,851</u> | <u>1,202</u> |

Source: Survey of NSW Maritime Private Moorings – June 2009 – Australian Marina Management P/L

Worthy of note is that, for Sydney Harbour alone, NSW Maritime has 1,202 applications on its waiting lists. This represents almost 25% of issued mooring licences for Sydney Harbour and strongly evidences the high demand for on-water boat storage in Sydney Harbour.

NSW Maritime mooring areas A and B are located east of Sydney Harbour Bridge. Areas C and D are located west of Sydney Harbour Bridge. Area E covers moorings both west and east of Sydney Harbour Bridge on the northern shores.

The NSW Maritime map of private mooring areas for Sydney Harbour is attached at Appendix 7.

Both marina berths and private moorings are discussed in more detail in the following sections of this study.

3. CURRENT SITUATION – WEST SYDNEY HARBOUR BOAT STORAGE

The following Tables C, D and E show summaries, at June 2009, of the berths and berth occupancies at the commercial, residential and boatshed marinas on both the southern shores and northern shores of Sydney Harbour to the west of Sydney Harbour Bridge.

TABLE C

COMMERCIAL MARINAS – WEST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF MARINA</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|--|---------------------|---------------|------------|--------------|
| Sydney Wharf 10 | Pymont Bay | 25 | 22 | 88.0 |
| Fish Markets Marina | Blackwattle Bay | 51 | 44 | 86.3 |
| Rozelle Superyacht Marina | Rozelle Bay | 24 | 24 | 100.0 |
| Balmain Marina | P'matta R. Balmain | 33 | 33 | 100.0 |
| Camerons Marina | P'matta R. Balmain | 16 | 15 | 93.8 |
| Birkenhead Point Marina | Iron Cove | 187 | 179 | 95.7 |
| Gladesville Bridge Marina | Five Dock Point | 50 | 48 | 96.0 |
| Cabarita Marina - Strata Berths) | Hen & Chicken Bay | 72 | 68 | 94.4 |
| d'Albora Marina Cabarita) | | 52 | 49 | 94.2 |
| River Quays Marina | P'matta R. Mortlake | 23 | 23 | 100.0 |
| Woolwich Marina | P'matta R. Woolwich | 19 | 18 | 94.7 |
| Woodleys Marina | Berrys Bay | 32 | 27 | 84.4 |
| TOTAL FOR 12 COMMERCIAL MARINAS | | 584 | 550 | 94.2 |

Source: Sydney Harbour Boat Storage Survey – June 2009 – Australian Marina Management Pty Ltd

The high level of demand for marina berths in the west Sydney area is clearly evident from the above Table. The management of these marinas report that occupancy is seasonal with the highest level of demand in the spring and summer seasons.

They also report that there has been a small contraction in demand for berths arising from the current economic downturn but without any serious adverse effect upon occupancies.

Owners on marina 'waiting lists' for berths have generally taken up any vacancies arising from vessel departures and many new owners of used vessels have chosen to retain the vessel at the marina from which it was purchased.

There are no sailing or boating club marinas in the west Sydney area.

3. CURRENT SITUATION – WEST SYDNEY HARBOUR BOAT STORAGE (CONTINUED)

Some relevant comments about the commercial marinas in the above Table are:-

- a) The Fish Markets Marina accommodates a number of commercial fishing vessels. It has 20 berths available for casual day visitation only and is usually fully occupied during weekend fish market trading periods;
- b) Balmain, Camerons, River Quays, Woolwich and Woodleys Marinas are all very small repair and service marinas with relatively few berths. These are older fixed-wharf or jetty type facilities and are generally in need of refurbishment or modernisation;
- c) Birkenhead Point, Gladesville Bridge and Cabarita (d’Albora) Marinas are larger marinas offering modern floating berth facilities for a wide range of boat sizes. These marinas are similar to the proposed Inner West Marina and are discussed later in this study.

TABLE D

RESIDENTIAL/PRIVATE MARINAS - WEST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF PROPERTY</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|---|------------------------|----------------------|-------------------|---------------------|
| Pier 6/7 Walsh Bay | Walsh Bay | 49 | 28 | 57.1 |
| Sydney Wharf 9 | Pyrmont Bay | 29 | 6 | 20.7 |
| Jones Bay Wharf | Jones Bay | 8 | 8 | 100.0 |
| Waterview Wharf Workshop | Mort Bay | 9 | 6 | 66.7 |
| Hopetoun Quays, Balmain | P'matta R. Balmain | 40 | 30 | 75.0 |
| Balmain Cove | Iron Cove | 31 | 25 | 80.6 |
| Abbotsford Cove | Abbotsford Bay | 13 | 12 | 92.3 |
| Cape Cabarita | France Bay | 23 | 18 | 78.3 |
| Hilly Street Mortlake | P'matta R. Mortlake | 16 | 10 | 62.5 |
| Pulpit Point | P'matta R. Pulpit Pt | 112 | 49 | 43.7 |
| Wondakiah, Wollstonecraft | Balls Head Bay | 41 | 27 | 65.9 |
| TOTAL FOR 11 RESIDENTIAL/PRIVATE MARINAS | | 371 | 219 | 59.0 |

Source: Sydney Harbour Boat Storage Survey – June 2009 – Australian Marina Management Pty Ltd

With one or two exceptions in those residential marinas with a small number of marina berths, the occupancy of berths in residential private marinas in the west Sydney area is low.

As previously stated, the 371 private residential berths represent 36.4% of the total berths (1,019) available in the west Sydney area but, of these, only 219, or 59% are occupied. None of these berths are available for use by vessel owners in the wider community.

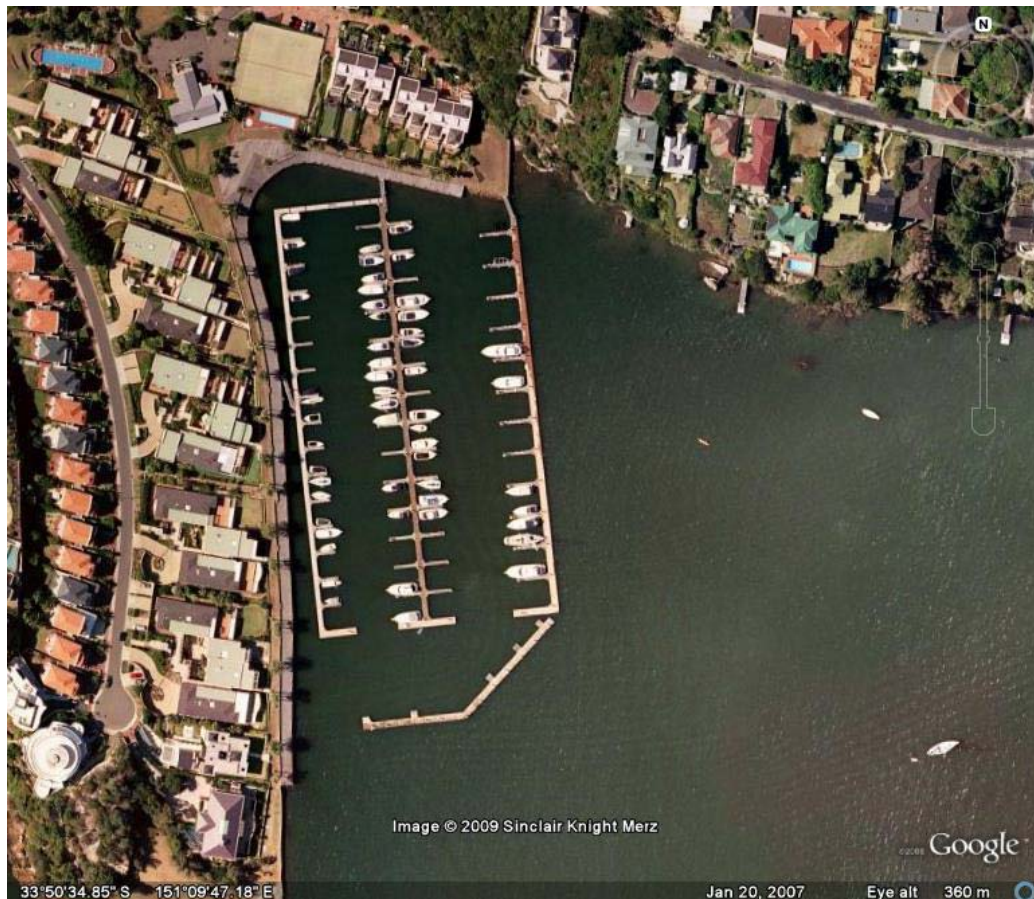
3. CURRENT SITUATION – WEST SYDNEY HARBOUR BOAT STORAGE (CONTINUED)

The residential marina at Pulpit Point is a notable example of private berths at residential marinas being under-utilised with the vacant berths not being available to meet the strong demand for such from other boat owners in the community.

Pulpit Point residential marina, at Hunters Hill, on the Parramatta River, was built in the late 1980s. It was designed with 112 berths, with one berth attached to each of the 112 residences at Pulpit Point developed by the then Londish Group as it was known.

Having regard to the current occupancy of Pulpit Point marina, and some of the other larger residential marinas, it is very clear that not all of the occupants of each and every residence desire to be boat owners.

In consequence, at Pulpit Point, there are sixty-three (63) vacant marina berths which have been vacant now for some 20 years and are not available to meet wider community demand.



Aerial view of Pulpit Point Marina showing vacant berths

3. CURRENT SITUATION – WEST SYDNEY HARBOUR BOAT STORAGE (CONTINUED)
TABLE E
COMMERCIAL BOATSHEDS - WEST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF BOATSHED</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|-------------------------------|----------------------|---------------|------------|--------------|
| Campbell Street Balmain | Mort Bay | 12 | 8 | 66.6 |
| Fountains Boatshed | Snails Bay | 12 | 12 | 100.0 |
| Cape Bouvard Marine | P'matta R. D'moyne | 4 | 4 | 100.0 |
| President Shipwright | P'matta R. D'moyne | 4 | 4 | 100.0 |
| Abbotsford Boatshed | P'matta Riv. Ab'ford | 0 | 0 | 0.0 |
| Waterview Rd Marine Centre | P'matta R. Putney | 10 | 10 | 100.0 |
| Woolwich Dock | Lane Cove R. W'wich | 8 | 3 | 37.5 |
| Stannard Marine | Berrys Bay | 14 | 12 | 85.7 |
| McMahons Point Boatshed | Lavender Bay | 0 | 0 | 0.0 |
| Lavender Bay Boatshed | Lavender Bay | 0 | 0 | 0.0 |
| TOTAL FOR 10 BOATSHEDS | | 64 | 53 | 82.8 |

Source: Sydney Harbour Boat Storage Survey – June 2009 – Australian Marina Management Pty Ltd

The occupancy of marina berths at the west of Sydney commercial boatshed facilities listed further demonstrates the high demand for on-water storage of vessels. Predominantly these facilities are vessel service and repair facilities and the berth occupancies at them is at a peak during the sailing and boating season.

TABLE F
CHARTER VESSEL BERTHING - WEST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF FACILITY</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|---------------------------------------|-----------------|---------------|------------|--------------|
| King Street Wharf | Darling Harbour | 7 | 7 | 100.0 |
| Sydney Aquarium | Darling Harbour | 8 | 8 | 100.0 |
| Jones Bay Wharf | Jones Bay | 26 | 22 | 84.6 |
| Blackwattle Bay Wharves | Blackwattle Bay | 13 | 13 | 100.0 |
| TOTAL FOR 4 CHARTER FACILITIES | | 54 | 50 | 92.6 |

Source: Sydney Harbour Boat Storage Survey – June 2009 – Australian Marina Management Pty Ltd

The Charter Vessel Association reports a shortage of suitable berthing facilities for charter vessels in Sydney Harbour generally thus adding to the demand for berthing at commercial marinas. Many charter vessels in Sydney currently use the older large commercial vessel wharves which have not been included in the June 2009 survey referred to.

3. CURRENT SITUATION – WEST SYDNEY HARBOUR BOAT STORAGE (CONTINUED)

In the previous section 2, Table B showed that, at June 2009, NSW Maritime had issued 4,851 private mooring licences for Sydney Harbour waterways. Of these licences, 2,512 are located west of Sydney Harbour Bridge. This is more than 50% of the issued mooring licences for Sydney Harbour and underlines the strong demand for on-water boat storage in the waterways west of Sydney Harbour Bridge.

For waterways west of Sydney Harbour Bridge, the following Table G sets out a summary of the issued NSW Maritime mooring licences at 30th June 2009 with the corresponding waiting list numbers for moorings for the area.

TABLE G

NSW MARITIME PRIVATE MOORING LICENCES

WEST OF SYDNEY HARBOUR BRIDGE

30TH JUNE 2009

| | <u>MOORING LICENCES</u> | <u>WAITING LISTS</u> |
|------------------------|------------------------------------|---------------------------------|
| SOUTHERN SHORES | 933 | 193 |
| NORTHERN SHORES | 1,579 | 93 |
| TOTAL MOORINGS | <u>2,512</u> | <u>286</u> |

Source: Survey of NSW Maritime Private Moorings – June 2009 – Australian Marina Management P/L

Of the 2,512 mooring licences issued for western Sydney waterways, only 933 are located on the southern shores – some 640 moorings less than those issued for the northern shores.

It is also noted that the waiting list totaling 193 moorings on the southern shores is more than 20% of the issued licences thereby demonstrating a strong and unsatisfied demand for on-water boat storage on the southern shores of west Sydney Harbour.

The above Table evidences that in the west Sydney Harbour area there is a known demand for on-water storage for 286 vessels. The proposed Inner West Marina will be well positioned to satisfy some of this evident demand.

As will be seen in a later section of this study, NSW Maritime has set a ceiling on the levels of moorings in Sydney Harbour. It is unlikely in the foreseeable future that there will be any increases in these private mooring licences. As a consequence, increased boat registrations will create added demand for marina berths at Inner West Marina Sydney.

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS

Existing demand patterns, trends and statistical data have been examined and are now reported upon as follows:-

- 4.1 NSW Recreational Vessel Registrations
- 4.2 NSW Recreational Boat Licences
- 4.3 NSW Recreational Vessel Private Moorings
- 4.4 Boat Size Distribution and Trends
- 4.5 Vessel Ownership Demand – Local Community

4.1 NSW Recreational Vessel Registrations

Statistics sourced from NSW Maritime Authority show the following patterns of growth in recreational vessel registrations for New South Wales. Individual statistics for Sydney Harbour are not available for all the periods shown.

NSW Recreational Vessel Registrations

| <u>Year</u> | <u>Total NSW</u> | <u>Annual Growth</u> | <u>Sydney Harbour</u> | <u>Annual Growth</u> |
|---------------------------------|----------------------|--------------------------|---------------------------|--------------------------|
| 1998-99 | 164,500 | + 2.17% | | |
| 1999-2000 | 170,000 | + 3.24% | | |
| 2000-01 | 179,800 | + 5.76% | | |
| 2001-02 | 184,200 | + 2.45% | | |
| 2002-03 | 191,089 | + 3.74% | | |
| 2003-04 | 196,234 | + 2.69% | 16,198 | |
| 2004-05 | 203,258 | + 3.58% | 16,515 | + 1.96% |
| 2005-06 | 209,382 | + 3.01% | 16,683 | + 1.02% |
| 2006-07 | 213,515 | + 1.97% | 16,839 | + 0.94% |
| 2007-08 | 217,183 | + 1.72% | 17,043 | + 1.21% |
| 2008-09 | 222,383 | + 2.39% | 17,144 | + 0.59% |
| <u>Average Per Annum Growth</u> | | | | |
| 1999 – 2009 | + 3.52% | | | |
| 2004 – 2009 | + 2.67% | | + 1.17% | |

In the 10 years from 1999 to 2009 the average annual increase in vessel registrations of 3.52% evidences the continuing long-term strong demand for recreational boat ownership.

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)**4.1 NSW Recreational Vessel Registrations (Continued)**

The annual growth rate in vessel registrations in the Sydney Harbour sector, whilst less than that for the State, nevertheless evidences continuing demand.

An examination of the foregoing summary of NSW and Sydney Harbour vessel registrations raises the question as to why the annual growth in vessel registrations for the Sydney Harbour sector has been consistently lower in the last 5 years than that for all of NSW.

The most likely reason is that, from the late 1990s to 2006, there was negligible growth in commercial marina berth capacity in Sydney Harbour. With the exception of the temporary Olympic marina in Rushcutters Bay (subsequently removed) no new marinas were built.

This was brought about predominantly by a moratorium being placed on marina berth expansion and development in Sydney Harbour by the then Carr State Government.

In the more recent years, 2006 to 2009, despite the lifting of the moratorium, there remains little increase in the berth capacity at the commercial marinas in Sydney Harbour.

Proposed plans for the expansion of marinas at Rose Bay, Point Piper and Double Bay remain unfulfilled whilst proposals for the expansion of other marinas in west Sydney Harbour have not reached any stage of submission to the appropriate consent authority and remain doubtful.

River Quays Marina, to the west of Breakfast Point on the Parramatta River, is adjacent to the northern boundary of the Breakfast Point residential estate. It is some 850 metres north and west around Breakfast Point from the site of the proposed Inner West Marina. In 2005/2006 proposals, to increase the number of berths at River Quays from 23 to 70, were submitted for consideration by NSW Maritime. The proponent could not agree terms with NSW Maritime and has withdrawn his proposal with the intention of pursuing the possibility of a re-development of his freehold land and closing the River Quays business.

Should this eventuate, the inner western area of Sydney Harbour would be left with only one marina at Cabarita with 124 berths of which 72 are privately owned "strata" berths.

The vessel registration data for the Sydney Harbour sector makes it clearly evident that the scarcity of marina berths in Sydney Harbour has acted as a heavy constraint to growth in boat ownership when compared to the total growth for the State.

It is already evident, from the survey of NSW Maritime private moorings discussed earlier, that there is demand for on-water boat storage for 1,202 vessels in Sydney Harbour.

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.1 NSW Recreational Vessel Registrations (Continued)

Since 1983, in 26 years, there has been substantial growth in recreational boat ownership in New South Wales. This is evidenced by the following Table H.

TABLE H
NSW RECREATIONAL VESSEL REGISTRATIONS
1983 - 2003 – 2009

| VESSEL SIZES (M) | NSW 1983 | % SIZE DISTRB'N | NSW 2003 | % SIZE DISTRIB'N | NSW 2009 | % SIZE DISTRIB'N |
|-------------------------|-----------------|------------------------|-----------------|-------------------------|-----------------|-------------------------|
| 0 - 3.99 | 25,636 | 27.27 | 65,688 | 34.37 | 67,446 | 30.33 |
| 4 - 5.99 | 63,760 | 67.84 | 100,863 | 52.78 | 121,546 | 54.66 |
| 6 - 7.99 | 3,321 | 3.53 | 13,006 | 6.80 | 18,829 | 8.47 |
| 8 - 9.99 | 663 | 0.71 | 5,476 | 2.86 | 6,497 | 2.92 |
| 10 - 11.99 | 365 | 0.39 | 3,657 | 1.91 | 4,476 | 2.01 |
| 12 - 13.99 | 137 | 0.15 | 1,528 | 0.83 | 2,114 | 0.95 |
| 14 - 15.99 | 62 | 0.07 | 550 | 0.29 | 910 | 0.40 |
| 16 - 17.99 | 29 | 0.03 | 185 | 0.09 | 310 | 0.14 |
| 18 - 19.99 | 14 | 0.01 | 83 | 0.04 | 150 | 0.07 |
| 20M & > | 5 | 0.00 | 53 | 0.03 | 105 | 0.05 |
| TOTAL | 93,992 | 100.00 | 191,089 | 100.00 | 222,383 | 100.00 |

Source: NSW Maritime Authority – Recreational Vessel Registration Data 1983, 2003 & 2009.

From 1983 to 2009 the total overall increase in NSW registrations has been for 128,391 vessels evidencing the strong community demand for recreational boat ownership.

Of particular note from Table H is the very substantial growth in demand for ownership of vessels of 8m in length and above. In 1983 there were 1,275 vessels registered with a length of 8m and above. At June 2009, there were 14,562 vessels registered with a length of 8m and above. This is a growth of 13,287 vessels.

It is these larger vessels which mostly require on-water storage. The very substantial and ongoing growth in ownership of these larger vessels results in a substantial increase in demand for marina berths. This is discussed in more detail in section 4.4.

Considering the lower than State-average vessel registration statistics for the Sydney Harbour sector, there is very likely to be a strong latent demand for marina berths in Sydney arising from those in the community who have refrained from purchasing vessels due to the lack of suitable and modern on-water vessel storage facilities in Sydney Harbour.

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.1 NSW Recreational Vessel Registrations (Continued)

From the summary set out at the beginning of this section it is noted that for the 5-year period 2004 – 2009 the average annual growth in vessel registrations for the whole of NSW was 2.67% pa whilst for the same period the average annual growth in registrations for the Sydney Harbour sector was a lower 1.17%pa.

In order to quantify the potential latent demand in Sydney Harbour, the following summary shows the expected level of registered vessels at June 2009 for the Sydney Harbour sector by applying the NSW average annual growth rate of 2.67% to the 2004 base of 16,198 vessels.

| | |
|--|---------------|
| Registered Vessels - Sydney Harbour sector - June 2004 | 16,198 |
| Applying NSW 5-year growth 2004-2009 (13.33%) | <u>2,159</u> |
| Notional Registered Vessels – Sydney Harbour – June 2009 | 18,357 |
| Actual Registered Vessels – Sydney Harbour – June 2009 | <u>17,144</u> |
| Potential Latent Demand – Vessels | <u>1,213</u> |

From Table H above, it can be calculated that of all NSW registered vessel 6.54% of these are 8m and above in length.

Of the potential latent demand for ownership of 1,213 vessels in the Sydney Harbour sector it is therefore calculated that 6.54%, or approximately 80, of these vessels would be of a size requiring on-water storage.

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.2 NSW Recreational Boat Licences

Statistics from NSW Maritime Authority, as set out below, show the trends in demand for recreational boat licences in New South Wales and for the Sydney Harbour sector. Licences held by persons interstate and overseas have been excluded from the statistics as have licences for personal water craft (PWCs) such as wave-runners and jet-skis.

| <u>Year</u> | <u>NSW Licences</u> | <u>NSW Growth</u> | <u>Sydney Hbr Licences</u> | <u>Sydney Hbr Growth</u> |
|---------------------------------|---------------------|-------------------|----------------------------|--------------------------|
| 2003-04 | 358,798 | -- | 34,632 | -- |
| 2004-05 | 371,366 | + 3.50% | 35,964 | + 3.85% |
| 2005-06 | 382,308 | + 2.95% | 37,086 | + 3.12% |
| 2006-07 | 388,416 | + 1.60% | 37,869 | + 2.11% |
| 2007-08 | 394,369 | + 1.53% | 38,708 | + 2.22% |
| 2008-09 | 421,943 | + 6.99% | 41,129 | + 6.25% |
| Average Annual Growth – 5 years | | + 3.52% | | + 3.75% |

The remarkable growth in boat licences in the 2008-09 year was due to the announcement by the Minister for Ports, The Hon Joe Tripodi MP, that in 2009, a compulsory practical boat handling component was to be added to the boat licence test requirements. This saw many applications being made for boat licences in the January to June 2009 period in order to avoid the practical boat handling component.

It is noted from the above summary that, with the exception of the unusual 2008-09 year, the growth in boat licences for the Sydney Harbour sector over the 5 years has been higher than for the State. Since 2004 NSW licences have shown an average annual growth rate of 3.52%. In the same period Sydney Harbour licences have had a higher average annual growth rate of 3.75%.

With the growth in recreational boat licences in Sydney Harbour being higher than that for NSW as a whole, it would be reasonable to expect that the growth in vessel registrations for Sydney Harbour would also be stronger than that for NSW.

The summary in section 4.1 however shows that Sydney Harbour vessel registration growth is lower than for NSW. This evidences the likelihood of a strong latent demand for boat ownership in Sydney Harbour sector unable to be fulfilled due to the considerable lack of available marina berths and on-water storage in Sydney Harbour

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.2 NSW Recreational Boat Licences (Continued)

To understand and quantify the potential latent demand for boat ownership in the Sydney Harbour sector, it is relevant to examine the ratios of recreational boat registrations to boat licences. For consistency, registrations and licences for personal water craft (PWCs) have been excluded as have interstate and overseas vessel registrations.

NSW Ratio of Boat Registrations to Boat Licences:

| <u>Year</u> | <u>NSW Only Registrations</u> | <u>NSW Only Licences</u> | <u>Vessels per 100 Licences</u> |
|-------------|-------------------------------|--------------------------|---------------------------------|
| 2003-04 | 182,857 | 358,798 | 50.96 |
| 2004-05 | 189,680 | 371,366 | 51.07 |
| 2005-06 | 195,513 | 382,308 | 51.14 |
| 2006-07 | 199,293 | 388,416 | 51.30 |
| 2007-08 | 202,520 | 394,369 | 51.35 |
| 2008-09 | 207,129 | 421,943 | 49.09 |

Clearly the rush to obtain licences prior to the introduction of the practical test component has impacted upon the ratio of boat registrations to boat licences for the 2009 year. It is expected that this will self-correct in the 2010 year in which a reduction in licence applications is anticipated.

Notwithstanding the 2009 year, the number of registered recreational vessels per 100 recreational boat licences for NSW has shown a consistent growth pattern clearly demonstrating a steady growth in demand for boat ownership. As a consequence this will generate a growth in demand for marina berths for those vessels 8m and above in length.

The same ratios are now examined for the Sydney Harbour sector.

Sydney Harbour Ratio of Boat Registrations to Boat Licences:

| <u>Year</u> | <u>Registrations</u> | <u>Licences</u> | <u>Vessels per 100 Licences</u> |
|-------------|----------------------|-----------------|---------------------------------|
| 2003-04 | 16,198 | 34,632 | 46.77 |
| 2004-05 | 16,515 | 35,964 | 45.92 |
| 2005-06 | 16,683 | 37,086 | 44.98 |
| 2006-07 | 16,839 | 37,869 | 44.47 |
| 2007-08 | 17,043 | 38,708 | 44.03 |
| 2008-09 | 17,144 | 41,129 | 41.68 |

As can be seen from the above summaries the ratio of registered vessels to boat licences is lower in Sydney Harbour than for NSW overall.

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.2 NSW Recreational Boat Licences (Continued)

Notwithstanding the lower ratio for the 2009 year impacted by the abnormal increase in licences, as discussed above, it is also noted that, for Sydney Harbour, there has been a small but consistent decline in boat ownership per 100 licences. This is in contrast to the ratio for NSW as a whole.

If the NSW ratio of vessel registrations per 100 licences at June 2009 (49.09) is applied to the June 2009 Sydney Harbour licences (41,129) then, at June 2009, the number of vessels registered for the Sydney Harbour area would be 20,190 (49.09 x 411.29). This is 3,046 vessels more than the 17,144 Sydney Harbour vessels actually registered at June 2009.

Clearly the 2009 figures have been influenced by the large abnormal increase in licences in the period. It would seem more prudent to use the end year 2008 data for such a comparison.

Thus, applying the total NSW ratio of registrations per 100 licences at June 2008 (51.35) to the 2008 Sydney Harbour licences (38,708), then, at June 2008, it is calculated that the number of vessels registered for Sydney Harbour would be 19,876 (51.35 x 387.08). This is 2,843 vessels more than the 17,043 vessels actually registered at June 2008.

These lower than total NSW ratios of boat ownership to licences indicate a likely strong latent demand in the Sydney Harbour area for boat ownership of all sizes of some 2,800 and 3,000 vessels.

From the earlier Table H in 4.1, it is noted that, at 30th June 2009 there are 14,562 vessels registered in NSW which are 8m and above in length. This represents 6.54% of total NSW registrations. It is the owners of these sized vessels who stimulate demand for modern marina berths.

Applying the 6.54% ratio of craft 8m and above in length to the calculated latent demand for boat ownership in Sydney Harbour of between 2,800 and 3,000 vessels, it is calculated that there is likely a latent demand in Sydney Harbour, at June 2009, for the ownership of between 183 and 196 additional vessels which would require marina berths.

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.3 NSW Recreational Vessel Private Moorings:

The following summary of NSW Maritime data is presented to show the situation with regards to private swing mooring licences issued by the Authority at 30th June each year.

| <u>Year</u> | <u>NSW Moorings</u> | <u>Sydney Hbr Moorings</u> |
|-------------|---------------------|----------------------------|
| 1995-96 | 13,700 | |
| 2000-01 | 13,900 | |
| 2001-02 | 14,150 | |
| 2002-03 | 14,200 | |
| 2003-04 | 15,000 | 4,862 |
| 2004-05 | 15,250 | 4,858 |
| 2005-06 | 15,449 | 4,861 |
| 2006-07 | 15,590 | 4,857 |
| 2007-08 | 15,722 | 4,855 |
| 2008-09 | 15,777 | 4,851 |

As evidenced from the above summary, between 1996 and 2003, there was only nominal growth in new private moorings licences issued throughout the State. This was partially due to NSW Maritime policy in some areas. Additional moorings have been released since 2003 but these have mainly been in The Hunter, North Coast and South Coast regions.

As can be seen from the statistics for Sydney Harbour above, private moorings since 2004 have remained relatively static. NSW Maritime currently has a ceiling on the levels of private mooring licences in Sydney Harbour and it is unlikely in the foreseeable future that there will be any increases in these.

Moorings licences for Sydney Harbour have clearly not kept pace with the growth in boat registrations thus increasing the demand for marina berth storage.

In section 3 of this study Table G sets out the NSW Maritime private mooring licences issued for west of Sydney Harbour Bridge with the corresponding applications for moorings on the waiting lists.

Detailed surveys of NSW Maritime mooring licences were conducted by Australian Marina Management Pty Limited at 30th April 2007, 30th November 2007, 1st September 2008 and 30th June 2009.

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.3 NSW Recreational Vessel Private Moorings (Continued):

The following Table I, extracted from these surveys, shows a comparison of the private mooring situation for the waterways west of Sydney Harbour Bridge.

TABLE I

NSW MARITIME - PRIVATE MOORINGS
WEST OF SYDNEY HARBOUR BRIDGE

| <u>SURVEY DATE</u> | <u>LICENCES</u> <u>ISSUED</u> | <u>WAITING</u> <u>LIST</u> | <u>% OF ISSUED</u> <u>LICENCES</u> |
|--------------------|----------------------------------|-------------------------------|---------------------------------------|
| 30th April 2007 | 2,513 | 246 | 9.79 |
| 30th November 2007 | 2,514 | 240 | 9.55 |
| 1st September 2008 | 2,512 | 231 | 9.19 |
| 30th June 2009 | 2,512 | 286 | 11.38 |

The summary set out earlier in this section showed that there has been no growth in NSW Maritime private moorings in Sydney Harbour for the last 5 years. This includes moorings west of Sydney Harbour Bridge.

Table I above shows that the waiting list for private moorings in the west Sydney area has remained for quite some time around 10% of existing moorings with a known demand for on-water boat storage for 286 vessels at June 2009.

As previously reported NSW Maritime has placed a ceiling on moorings in Sydney Harbour and thus the prospect of the 286 applicants on the waiting lists obtaining moorings in the near future is highly unlikely.

The proposed Inner West Marina therefore offers opportunity to satisfy the evident demand of boat owners for on-water storage.

Owners of larger vessels have a considerable investment in them. Members of the Marina Association of NSW report that these owners are generally not prepared to moor their vessels on a swing mooring whether it is a commercial or private mooring. There is the constant risk of damage from other vessels breaking free from moorings as well as from theft and vandalism. There is also a strong safety factor to be considered when accessing larger vessels from dinghies in adverse weather conditions.

Clearly the strongest demand is for berthing at a modern marina berth which provides owners with security and protection as well as safety in accessing their vessels.

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.4 NSW Boat Size Distribution and Trends:

Table H, as set out below, is brought forward from section 4.1 for further discussion.

Table H
NSW RECREATIONAL VESSEL REGISTRATIONS
BOAT SIZE DISTRIBUTION COMPARISONS
1983 - 2003 - 2009

| VESSEL SIZES (M) | NSW 1983 | % SIZE DISTRB'N | NSW 2003 | % SIZE DISTRIB'N | NSW 2009 | % SIZE DISTRIB'N |
|------------------|---------------|-----------------|----------------|------------------|----------------|------------------|
| 0 - 3.99 | 25,636 | 27.27 | 65,688 | 34.37 | 67,446 | 30.33 |
| 4 - 5.99 | 63,760 | 67.84 | 100,863 | 52.78 | 121,546 | 54.66 |
| 6 - 7.99 | 3,321 | 3.53 | 13,006 | 6.80 | 18,829 | 8.47 |
| 8 - 9.99 | 663 | 0.71 | 5,476 | 2.86 | 6,497 | 2.92 |
| 10 - 11.99 | 365 | 0.39 | 3,657 | 1.91 | 4,476 | 2.01 |
| 12 - 13.99 | 137 | 0.15 | 1,528 | 0.83 | 2,114 | 0.95 |
| 14 - 15.99 | 62 | 0.07 | 550 | 0.29 | 910 | 0.40 |
| 16 - 17.99 | 29 | 0.03 | 185 | 0.09 | 310 | 0.14 |
| 18 - 19.99 | 14 | 0.01 | 83 | 0.04 | 150 | 0.07 |
| 20M & > | 5 | 0.00 | 53 | 0.03 | 105 | 0.05 |
| TOTAL | 93,992 | 100.00 | 191,089 | 100.00 | 222,383 | 100.00 |

Source: NSW Maritime Authority – Recreational Vessel Registration Data 1983, 2003 & 2009.

Marina Industry operatives generally report that it is the owners of vessels of a length of 8m and above who create the demand for marina berth storage for their vessels.

Table H clearly shows the enormous growth in 26 years in the number of vessels requiring on-water storage and marina berthing.

At June 1983 there were 1,275 registered vessels of a length of 8m and above. This amounted to 1.36% of the total NSW recreational vessel registrations.

By June 2003, twenty years later, registered vessels 8m and above in length had grown to a total of 11,532 vessels representing 6.03% of total NSW recreational vessel registrations.

At June 2009, registered vessels 8m and above in length had increased by 3,030 vessels to a total of 14,562 vessels representing an increased 6.55% of total NSW recreational vessel registrations.

Numerically, in the 26-year period from 1983 to 2009, in NSW, there has been an increase in the ownership of boats, 8.0m and above in length, of 13,287 vessels.

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.4 NSW Boat Size Distribution and Trends (Continued):

This equates to an average increase of over 500 vessels each year in NSW with the consequent increase in the demand for modern marina berths and boat storage facilities.

As stated earlier in this study, marina industry operatives have reported that owners of larger vessels do not wish to locate their vessels on swing moorings. They consider swing moorings a risk environment and expect, in the twenty-first century, to have their vessels moored at a modern and secure marina berth with safer and more appropriately managed access.

The following 25-year comparative summary in Table J shows the trends in boat size demand for the 20 year period from 1983 to 2003 and for the 5-year period from 2003 to 2008.

TABLE J
NSW RECREATIONAL VESSEL REGISTRATIONS
20 & 25 YEAR GROWTH TRENDS - VESSELS 8.0M AND ABOVE
1983 – 2003 - 2008

| VESSEL SIZE (M) | No OF VESSELS 1983 | No OF VESSELS 2003 | 20 YEAR INCREASE FROM 1983 | AVERAGE ANNUAL INCREASE | No OF VESSELS 2008 | 5 YEAR INCREASE FROM 2003 | AVERAGE ANNUAL INCREASE |
|-----------------|--------------------|--------------------|----------------------------|-------------------------|--------------------|---------------------------|-------------------------|
| 8.0 - 9.99 | 663 | 5,476 | 4,813 | 241 | 6,391 | 915 | 183 |
| 10.0 - 11.99 | 365 | 3,657 | 3,292 | 165 | 4,419 | 762 | 153 |
| 12.0 - 13.99 | 137 | 1,528 | 1,391 | 70 | 2,065 | 537 | 107 |
| 14.0 - 15.99 | 62 | 550 | 488 | 24 | 863 | 313 | 63 |
| 16.0 - 17.99 | 29 | 185 | 156 | 8 | 286 | 101 | 20 |
| 18.0 - 19.99 | 14 | 83 | 69 | 4 | 142 | 59 | 12 |
| 20.0 & > | 5 | 53 | 48 | 2 | 97 | 44 | 9 |
| | 1,275 | 11,532 | 10,257 | 514 | 14,263 | 2,731 | 547 |
| | | | | | | | |

Source: NSW Maritime Authority – Recreational Vessel Registration Data 1983, 2003 & 2008

There are two prominent trends indicated by the above Table. These are:-

- i) The average annual increase in total ownership of vessels 8.0m and above in length in NSW continues to rise. It has increased from an average of 514 vessels per year from 1983 to 2003 to an average of 547 vessels per year in the following five years to 2008. This continued growth increases the demand by discerning boat owners for modern and efficient marina berths in NSW;

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.4 NSW Boat Size Distribution and Trends (Continued):

ii) Of more importance to planners is the clear trend shown by Table J in the growth in ownership of larger vessels.

Firstly it is noted that the average annual growth in ownership of vessels **8.0m to 9.99m** in length in the last 5 years has contracted from an average of 241 new vessels per year (from 1983 to 2003) to an average of 183 new vessels per year (from 2003 to 2008) notwithstanding the average annual increase in overall vessel ownership from 514 to 575 vessels per year.

New vessels entering the market in the size range **10.0 to 11.99m** have remained basically static at around 160 new vessels per year.

It is for vessels **12.0m and above** where the Table evidences remarkable growth in ownership of larger vessels as follows:-

| <u>Vessel Size Range</u> | <u>Average Annual Increase (1983 – 2003)</u> | <u>Average Annual Increase (2003 – 2008)</u> | <u>Variance</u> |
|----------------------------|--|--|-----------------|
| 12.0 – 13.99m | 70 | 107 | +52.86% |
| 14.0 – 15.99m | 24 | 63 | +162.50% |
| 16.0 – 17.99m | 8 | 20 | +150.00% |
| 18.0 – 19.99m | 4 | 12 | +200.00% |
| 20m and above | 2 | 9 | +350.00% |
| Total 12.0m – 20m + | 108 | 211 | + 95.37% |

It should be noted here that the vessels in the size categories listed above, due to vessel lengths, weights and wind and wave action, are generally not suited to being placed on swing moorings.

Clearly the owners of these vessels will be seeking appropriate and suitable vessel on-water storage facilities thus increasing the strong demand for modern marina berths.

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.5 Vessel Ownership Demand – Inner West Marina Catchment

Within the Sydney Metropolitan area the proposed Inner West Marina is very centrally located. Many new road networks in Sydney were developed for the Sydney 2000 Olympics held at Olympic Park Homebush in close proximity to Breakfast Point and the proposed Inner West Marina site. These established road networks make Inner West Marina Sydney very accessible from Sydney’s northern, western and southern suburbs.

Whilst demand for berthing at Inner West Marina will be generated from the wider NSW sailing and boating community, it is expected to be mainly derived, not only from nearby residents on both sides of Parramatta River, but from residents of Sydney suburbs able to access Breakfast Point by road within 30 to 40 minutes.

With reference to the map below, it is anticipated that the catchment for berth demand at Inner West Marina will be derived from an area running from Sydney – North Sydney – Chatswood – Hornsby – Baulkham Hills – Parramatta – Bankstown – Canterbury – Sydney.

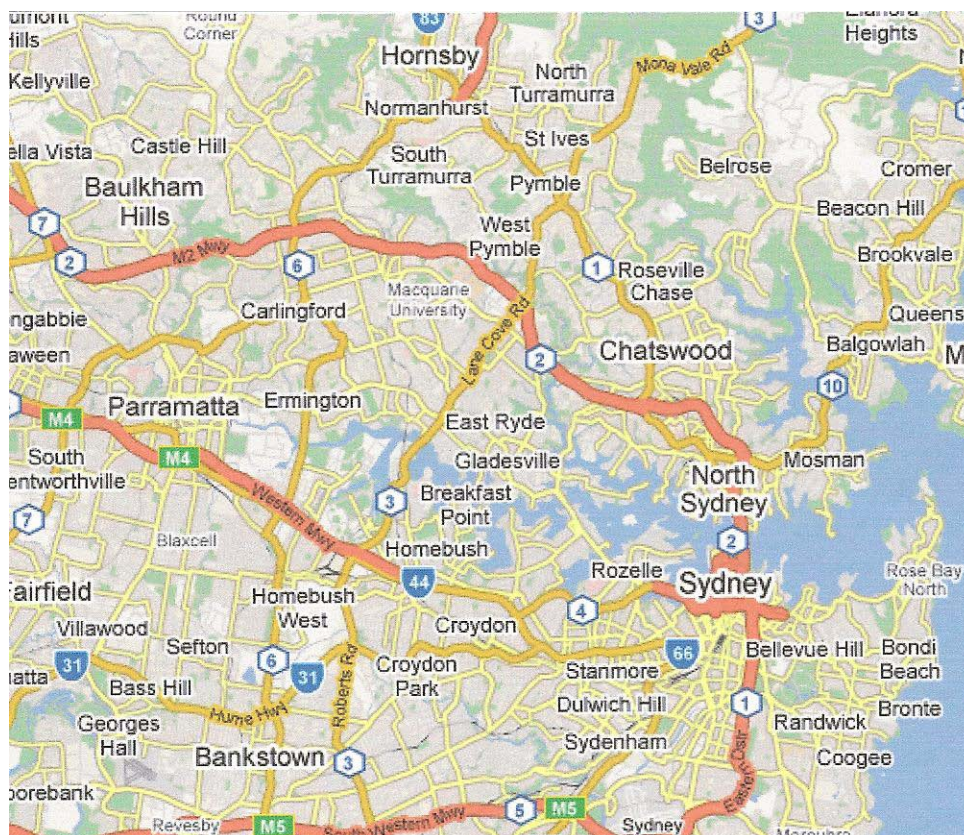


Figure 1: Map showing Breakfast Point and surrounding Sydney suburbs

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.5 Vessel Ownership Demand – Inner West Marina Catchment (Continued)

The Sydney and suburbs Local Government Areas (LGAs) which are anticipated to provide the catchment sources for berthing at Inner West Marina are:

South of Parramatta River

- Ashfield
- Auburn
- Bankstown
- Burwood
- Canterbury
- Canada Bay
- Leichhardt
- Marrickville
- Strathfield
- Sydney

North of Parramatta River

- Baulkham Hills (Inner)
- Hornsby
- Hunters Hill
- Ku-ring-gai
- Lane Cove
- North Sydney
- Parramatta
- Ryde
- Willoughby

For the anticipated Inner West Marina catchment area the boat ownership statistics for residents of the foregoing LGAs are shown in the following Table K at 30th June 2006 and three years later at 30th June 2009. The boat sizes shown are 8m in length and above being the size of vessels most likely to drive the demand for marina berthing at the Inner West Marina.

TABLE K
Vessel Ownership - Inner West Marina Catchment LGAs

| Vessel Sizes | 2006 | | 2009 | | 3-Year Growth | |
|---------------|--------------|---------------|--------------|---------------|---------------|---------------|
| | Vessels | % Distr | Vessels | % Distr | Vessels | Growth % |
| 8.0 - 9.99m | 1,840 | 46.68 | 1,938 | 44.48 | 98 | 5.33% |
| 10.0 - 11.99m | 1,262 | 32.01 | 1,400 | 32.13 | 138 | 3.01% |
| 12.0 - 13.99m | 523 | 13.27 | 589 | 13.52 | 66 | 12.62% |
| 14.0 - 15.99m | 209 | 5.30 | 278 | 6.38 | 69 | 33.01% |
| 16.0 - 17.99m | 62 | 1.57 | 81 | 1.86 | 19 | 30.65% |
| 18.0 - 19.99m | 19 | 0.48 | 35 | 0.80 | 16 | 84.21% |
| 20m & > | 27 | 0.69 | 36 | 0.83 | 9 | 33.33% |
| Total | 3,942 | 100.00 | 4,357 | 100.00 | 415 | 10.53% |
| | | | | | | |

Source: NSW Maritime Authority – Recreational Vessel Registration – By Size and Post Codes - 2006 & 2009

As from other summaries of vessel size distribution included in this study, the above Table K again evidences the trend towards ownership of larger vessels requiring marina berthing.

4. EXISTING DEMAND PATTERNS, TRENDS AND STATISTICS (CONTINUED)

4.5 Vessel Ownership Demand – Inner West Marina Catchment (Continued)

For comparison the following Table L shows the NSW State growth, from 2006 to 2009, in ownership of vessels 8m in length and above.

TABLE L

Vessel Ownership - NSW State

| Vessel Sizes | 2006 | | 2009 | | 3-Year Growth | |
|---------------|---------|--------|---------|--------|---------------|----------|
| | Vessels | % | Vessels | % | Vessels | Growth % |
| 8.0 - 9.99m | 6,156 | 45.67 | 6,497 | 44.61 | 341 | 5.54% |
| 10.0 - 11.99m | 4,229 | 31.37 | 4,476 | 30.74 | 247 | 5.84% |
| 12.0 - 13.99m | 1,899 | 14.09 | 2,114 | 14.52 | 215 | 11.32% |
| 14.0 - 15.99m | 744 | 5.52 | 910 | 6.25 | 166 | 22.31% |
| 16.0 - 17.99m | 240 | 1.78 | 310 | 2.13 | 70 | 29.17% |
| 18.0 - 19.99m | 123 | 0.91 | 150 | 1.03 | 27 | 21.95% |
| 20m & > | 89 | 0.66 | 105 | 0.72 | 16 | 17.98% |
| Total | 13,480 | 100.00 | 14,562 | 100.00 | 1,082 | 8.03% |
| | | | | | | |

Comparing Table L with Table K it is noted that the 3-year growth rate for boat ownership in the Inner West Marina catchment is 10.53% which is above the NSW growth rate of 8.03%, notwithstanding, as discussed earlier that the growth in registrations for Sydney Harbour has been lower than that for NSW.

As it has implications for the berth size distribution for the proposed Inner West Marina, a comparison of the foregoing tables evidences that, in the Inner West Marina catchment, the demand for vessels 8m to 11.99m is lower than for NSW as a whole whilst demand for vessels above 12m is much higher than for the State.

This again confirms the trend towards the ownership of larger vessels than has been seen in previous decades. This is an issue which needs to be addressed when planning the design of modern marinas.

5. ANTICIPATED DEMAND PROJECTIONS 2010, 2020 & 2030

The following Tables show the anticipated future projections for ownership of vessels in NSW of a length 8m and above being the size of vessels which drive the demand for marina berths. The anticipated demand projections have been calculated to show the growth from three bases:-

- The three-year period 2006 to 2009 (Short Term Base);
- The six-year period 2003 to 2009 (Medium Term Base); and
- The twenty-six year period 1983 to 2009 (Long Term Base).

From these three bases the anticipated future vessel ownership in NSW for the years 2010, 2020 and 2030 has been calculated using the average growth factor arising from each base.

Table M below has been based upon the three-year growth pattern from June 2006 to June 2009. Reference to the summary of NSW Vessel Registrations in section 4.1 shows that new vessel registrations, in the years to June 2007 (+1.97%) and June 2008 (+1.72%) fell below the 1999-2009 average annual growth of 3.52% and the 2004-2009 average annual growth of 2.67%. This is an important reason for using this 3-year base as lower median.

An added reason that the Short Term Base of 2006 – 2009 has been chosen is because the years ending June 2007 to June 2009 were years in which economic factors, including high interest rates and/or recessionary pressures may have had a dampening effect on new vessel purchases.

TABLE M

SHORT TERM- 2006 BASE USING AVERAGE 3-YEAR GROWTH PATTERN TO 2009

| Vessel Sizes (m) | Vessels 2006 | Vessels 2009 | 3-Year Growth | % Growth P/Annum | Anticipated Vessel Ownership | | |
|------------------|---------------|---------------|---------------|------------------|------------------------------|---------------|---------------|
| | | | | | 2010 | 2020 | 2030 |
| 8 - 9.99 | 6,151 | 6,497 | 346 | 1.88% | 6,613 | 7,770 | 8,926 |
| 10 - 11.99 | 4,227 | 4,476 | 249 | 1.96% | 4,558 | 5,387 | 6,217 |
| 12 - 13.99 | 1,899 | 2,114 | 215 | 3.77% | 2,185 | 2,901 | 3,617 |
| 14 - 15.99 | 744 | 910 | 166 | 7.44% | 965 | 1,518 | 2,072 |
| 16 - 17.99 | 240 | 310 | 70 | 9.72% | 333 | 566 | 799 |
| 18 - 19.99 | 123 | 150 | 27 | 7.32% | 159 | 249 | 339 |
| 20m & > | 89 | 105 | 16 | 5.99% | 110 | 163 | 216 |
| TOTAL | 13,473 | 14,562 | 1,089 | Average | 14,923 | 18,554 | 22,186 |

The above Table shows that, using the short term basis, the predicted growth in new vessels of a size 8m and above in length will average 363 per year. The table also highlights however that there is a much higher rate of growth in ownership of larger size vessels of 12m and above in length compared to those in the 8.0 – 11.99m range.

5. ANTICIPATED DEMAND PROJECTIONS (CONTINUED)

Table N below has been based on a more “medium” term of growth for the six years 2003 to 2009 in which (as can be calculated from the summary in section 4.1) the average annual growth rate in new vessels registrations was 2.73%.

TABLE N
MEDIUM TERM - 2003 BASE USING AVERAGE 6-YEAR GROWTH PATTERN TO 2009

| Vessel Sizes (m) | Vessels 2003 | Vessels 2009 | 6-Year Growth | % Growth P/Annum | Anticipated Vessel Ownership | | |
|------------------|---------------|---------------|---------------|------------------|------------------------------|---------------|---------------|
| | | | | | 2010 | 2020 | 2030 |
| 8 - 9.99 | 5,476 | 6,497 | 1,021 | 3.11% | 6,668 | 8,371 | 10,074 |
| 10 - 11.99 | 3,657 | 4,476 | 819 | 3.73% | 4,612 | 5,976 | 7,340 |
| 12 - 13.99 | 1,528 | 2,114 | 586 | 6.39% | 2,211 | 3,187 | 4,163 |
| 14 - 15.99 | 550 | 910 | 360 | 10.91% | 970 | 1,570 | 2,170 |
| 16 - 17.99 | 185 | 310 | 125 | 11.26% | 331 | 539 | 747 |
| 18 - 19.99 | 83 | 150 | 67 | 13.45% | 161 | 273 | 385 |
| 20m & > | 53 | 105 | 52 | 16.35% | 114 | 201 | 288 |
| TOTAL | 11,532 | 14,562 | 3,030 | Average | 15,067 | 20,117 | 25,167 |

The above Table shows that using this “medium” term basis, the growth in new vessels of a size 8m and above in length averages 505 vessels per year. The Table again highlights the strong demand for ownership of vessels in the size range 12m and above in length.

The following Table O has been calculated using the long-term twenty-six (26) year growth statistics from 1983 to 2009. As can be calculated from Table H in section 4.1, in this 26-year period, the average annual growth in total NSW vessel registrations was 5.24%.

TABLE O
LONG TERM - 1983 BASE USING AVERAGE 26-YEAR GROWTH PATTERN TO 2009

| Vessel Sizes (m) | Vessels 1983 | Vessels 2009 | 26-Year Growth | % Growth P/Annum | Anticipated Vessel Ownership | | |
|------------------|--------------|---------------|----------------|------------------|------------------------------|---------------|---------------|
| | | | | | 2010 | 2020 | 2030 |
| 8 - 9.99 | 663 | 6,497 | 5,834 | 33.84% | 6,721 | 8,964 | 11,207 |
| 10 - 11.99 | 365 | 4,476 | 4,111 | 43.32% | 4,634 | 6,215 | 7,796 |
| 12 - 13.99 | 137 | 2,114 | 1,977 | 55.50% | 2,190 | 2,950 | 3,710 |
| 14 - 15.99 | 62 | 910 | 848 | 52.60% | 943 | 1,269 | 1,595 |
| 16 - 17.99 | 29 | 310 | 281 | 37.27% | 321 | 429 | 537 |
| 18 - 19.99 | 14 | 150 | 136 | 37.36% | 155 | 207 | 259 |
| 20m & > | 5 | 105 | 100 | 76.92% | 109 | 148 | 186 |
| TOTAL | 1,275 | 14,562 | 13,287 | | 15,073 | 20,182 | 25,290 |

5. ANTICIPATED DEMAND PROJECTIONS (CONTINUED)

Table O on the previous page shows that using the “long-term” term basis, the predicted growth in new vessels of a size 8m and above in length averages 511 vessels per year. The predicted demand using this “long-term” base is not dissimilar to the predicted demand using the “medium-term” base.

Table P below now summarises the predicted levels of boat ownership of vessels 8m and above in length at 2010, 2020 and 2030 using all three methods discussed above.

**TABLE P
GROWTH PATTERNS AND ANTICIPATED OWNERSHIP**

SUMMARY OF PROJECTIONS BASED ON SHORT, MEDIUM & LONG TERM BASES

| Vessel Sizes (m) | Actual 2009 | Anticipated Vessels - Year 2010 | | | Anticipated Vessels - Year 2020 | | | Anticipated Vessels - Year 2030 | | |
|-----------------------|----------------|------------------------------------|-------------|--------------|------------------------------------|-------------|--------------|------------------------------------|-------------|--------------|
| | | Short Term | Med Term | Long Term | Short Term | Med Term | Long Term | Short Term | Med Term | Long Term |
| 8 - 9.99 | 6,497 | 6,613 | 7,770 | 8,926 | 6,668 | 8,371 | 10,074 | 6,721 | 8,964 | 11,207 |
| 10 - 11.99 | 4,476 | 4,558 | 5,387 | 6,217 | 4,612 | 5,976 | 7,340 | 4,634 | 6,215 | 7,796 |
| 12 - 13.99 | 2,114 | 2,185 | 2,901 | 3,617 | 2,211 | 3,187 | 4,163 | 2,190 | 2,950 | 3,710 |
| 14 - 15.99 | 910 | 965 | 1,518 | 2,072 | 970 | 1,570 | 2,170 | 943 | 1,269 | 1,595 |
| 16 - 17.99 | 310 | 333 | 566 | 799 | 331 | 539 | 747 | 321 | 429 | 537 |
| 18 - 19.99 | 150 | 159 | 249 | 339 | 161 | 273 | 385 | 155 | 207 | 259 |
| 20m & > | 105 | 110 | 163 | 216 | 114 | 201 | 288 | 109 | 148 | 186 |
| TOTAL | 14,562 | 14,923 | 18,554 | 22,186 | 15,067 | 20,117 | 25,167 | 15,073 | 20,182 | 25,290 |

Industry reports indicate that the demand for ownership of vessels in the larger size range accelerated from the mid 1990s and thus the predictions above using the “long-term” basis, due to the length of the basis in terms of time, do not accurately reflect the more recent and current demand patterns.

The foregoing Table clearly evidences the continuing strong demand for ownership of vessels of the size which require on-water storage including modern marina berthing with associated service facilities.

It is considered reasonable that a prediction of boat ownership, based on an average of the “short-term” and “medium-term” forecasts in Table P, would be achievable subject to:

- availability of modern marina berths and on-water boat storage facilities
- a stable economy
- no unforeseen events which could adversely affect boating or boat ownership

5. ANTICIPATED DEMAND PROJECTIONS (CONTINUED)

On those assumptions, the demand for boat ownership in NSW of vessels 8m and above in length could be expected to achieve the following levels of registered recreational vessels at June 2010, 2020 and 2030:-

| <u>Vessel Size</u> | <u>2010</u> | <u>2020</u> | <u>2030</u> |
|-------------------------------|---------------|---------------|---------------|
| 8.0m – 9.99m | 6,640 | 8,070 | 9,500 |
| 10.0m – 11.99m | 4,580 | 5,680 | 6,780 |
| 12.0m – 13.99m | 2,200 | 3,040 | 3,890 |
| 14.0m – 15.99m | 970 | 1,540 | 2,120 |
| 16.0m – 17.99m | 330 | 550 | 770 |
| 18.0m – 19.99m | 160 | 260 | 360 |
| 20m & above | 110 | 180 | 250 |
| Forecast Total Vessels | 14,990 | 19,320 | 23,670 |

The foregoing predictions reflect a continuing strong demand for the ownership of vessels which in turn will continue to drive a strong demand for modern marina berthing.

At June 2009 of the 14,562 vessels registered in NSW of a length 8m and above, 6,959 of these were sailing vessels representing approximately 48% of total registered vessels.

There is no evidence to demonstrate that the future ratio of registered sailing vessels to power vessels will not remain fairly evenly shared.

For the anticipated demand predictions set out above, it is thus reasonable to anticipate that approximately half of the vessel numbers shown will represent sailing vessels.

6. BERTH SIZE DISTRIBUTION

Inner West Marina Sydney has been planned to have a wide range of berths as follows:

| <u>Berth Size (Vessel Length)</u> | <u>Permanent Berths</u> | <u>Temporary Berths</u> |
|---------------------------------------|-----------------------------|-----------------------------|
| 8m | 12 | - |
| 10m | 30 | - |
| 12m | 42 | 4 |
| 14m | 40 | - |
| 16m | 28 | - |
| 18m | 6 | 1 |
| 20m | 7 | - |
| 25m | 2 | - |
| <u>Total Berths</u> | <u>167</u> | <u>5</u> |

A plan of Inner West Marina at Appendix 1 shows the proposed layout.

The trend towards ownership of larger vessels has been evidenced in earlier sections of this study. It is a trend which became evident in the early to mid 1990s and has continued at an increasing rate since then.

With increasing affluence and leisure time within the community the trend to ownership of larger vessels is also forecast to continue well into the future. Industry reports show that Australian and overseas boat manufacturers, having done extensive research, are continuing to design and launch larger vessel models to cater for the forecast future demand for ownership of them

This of course has implications for marina planning which needs to be done with at least a 30 year window to the future considering the improved and expected life of today’s modern marina systems and associated piling.

To address the berth size distribution requirements for the proposed Inner West Marina Sydney, the vessel registration data for the expected Inner West Marina catchment area, described in section 4.5, has been used.

To the 2006 base, the average annual growth rate for the 3 years 2006 to 2009 has been applied to forecast future vessel ownership in the Inner West Marina catchment.

As discussed previously using the 3-year growth factor is the lowest and therefore the most conservative. For vessels sized 8m and above in length, the following Table Q shows the anticipated boat ownership in the Inner West Marina catchment for 2020, 2030 and 2040.

6. BERTH SIZE DISTRIBUTION (CONTINUED)

TABLE Q

INNER WEST MARINA CATCHMENT - ANTICIPATED VESSEL OWNERSHIP

SHORT TERM- 2006 BASE USING AVERAGE 3-YEAR GROWTH PATTERN TO 2009

| Vessel Sizes (m) | Vessels 2006 | Vessels 2009 | 3-Year Growth | % Growth P/Annum | Anticipated Vessel Ownership | | |
|------------------|--------------|--------------|---------------|------------------|------------------------------|-------|-------|
| | | | | | 2020 | 2030 | 2040 |
| 8 - 9.99 | 1,840 | 1,938 | 98 | 1.78% | 2,200 | 2,528 | 2,855 |
| 10 - 11.99 | 1,262 | 1,400 | 138 | 3.65% | 1,769 | 2,230 | 2,691 |
| 12 - 13.99 | 523 | 589 | 66 | 4.21% | 765 | 985 | 1,205 |
| 14 - 15.99 | 209 | 278 | 69 | 11.00% | 462 | 692 | 922 |
| 16 - 17.99 | 62 | 81 | 19 | 10.21% | 132 | 195 | 258 |
| 18 - 19.99 | 19 | 35 | 16 | 28.07% | 78 | 128 | 178 |
| 20m & > | 27 | 36 | 9 | 11.11% | 60 | 90 | 120 |
| TOTAL | 3,942 | 4,357 | 415 | Average | 5,466 | 6,848 | 8,229 |

Using the anticipated year 2040 boat ownership data for the Inner West Marina catchment from above, the following Table R shows the size distribution ratio of vessels compared to the planned berth size distribution ratio for the proposed Inner West Marina.

TABLE R

INNER WEST MARINA - BERTH SIZE DISTRIBUTION COMPARISON

| <u>INNER WEST MARINA</u> | | | <u>INNER WEST MARINA CATCHMENT</u> | | |
|--------------------------|--------------|-----------|------------------------------------|---------------|--------|
| TOTAL BERTHS | | | ANTICIPATED BOAT OWNERSHIP | | |
| Boat Size | No of Berths | % Distrbn | Vessel Sizes | Forecast 2040 | |
| | | | | Vessels | % |
| 8m | 12 | 6.98 | 8.0 - 9.99m | 2,855 | 34.70 |
| 10m | 30 | 17.44 | 10.0 - 11.99m | 2,691 | 32.70 |
| 12m | 46 | 26.74 | 12.0 - 13.99m | 1,205 | 14.64 |
| 14m | 40 | 23.26 | 14.0 - 15.99m | 922 | 11.20 |
| 16m | 28 | 16.28 | 16.0 - 17.99m | 258 | 3.14 |
| 18m | 7 | 4.07 | 18.0 - 19.99m | 178 | 2.16 |
| 20m | 7 | 4.07 | 20m & > | 120 | 1.46 |
| 25m | 2 | 1.16 | | | |
| Total | 172 | 100.00 | Total | 8,229 | 100.00 |

6. BERTH SIZE DISTRIBUTION (CONTINUED)

Due to some water depth constraints within the proposed marina near the shoreline, Inner West Marina Sydney has been planned with twelve (12) berths designed for vessels limited to 8m in length overall.

In addition, the berth size distribution fully recognises the implications for the future long-term suitability of the marina by planning larger berths above the ratio of expected boat size ownership in the catchment area as shown above.

Comparison of the two summaries in Table R above shows that for vessels ranging from 8m up to 12m in length, Inner West Marina provides 51% of its berths for these vessels against a ratio of 67% of anticipated vessels of these sizes in the catchment area in the year 2040.

For vessels in the range of over 12m to 16m in length however, Inner West Marina has been designed for over 39% of its berths to cater for these sized vessels compared with almost 26% of the ratio of the anticipated year 2040 boat ownership.

From a professionally operational perspective it is considered that the berth size distribution planned for the proposed Inner West Marina is both sensible and prudent.

The planned higher ratio of larger berths gives Inner West Marina management a desirable degree of long-term flexibility to cater for the ever changing demographics of boat ownership.

It is usually always possible to place a small craft in a larger berth space but it is not possible to locate larger vessels in smaller berth spaces.

It is considered that the marina design and berth size distribution allows Inner West Marina management the flexibility to satisfy demands for boat owners well beyond the year 2040 thus avoiding the potential disruption and cost of reconfiguring the marina within its expected life.

7. ANTICIPATED BOAT TYPES & PROFILES

As stated in the Introduction to this study, TLB Engineers has requested Australian Marina Management Pty Limited to comment upon the profile of vessels which are most likely to make up the demand for berthing at Inner West Marina Sydney.

On 29th June 2009 Australian Marina Management Pty Limited conducted a survey of the three (3) main commercial marinas west of Sydney Harbour Bridge on the southern shores of Sydney Harbour’s Parramatta River.

The marinas surveyed were:

- Birkenhead Point Marina – 187 berths
- Gladesville Bridge Marina – 50 berths
- d’Albora Cabarita Marina – 124 berths

The survey was undertaken to determine the types and height profiles of the vessels berthing at these marinas and from which the types and profiles of vessels likely to be berthing at the proposed Inner West Marina Sydney may be anticipated.

Table S below shows a summary of the vessels observed at each marina. Yachts, whilst having masts have a low hull and deck profile. Cruisers, or power vessels, generally come in two categories, the sports, or express, cruiser with a low hull and deck profile and fly-bridge cruisers with an upper deck and thus a higher profile.

TABLE S
BOAT PROFILES
PARRAMATTA RIVER COMMERCIAL MARINAS

| VESSEL TYPE | PROFILE | BIRKENHEAD POINT | | GLADESVILLE BRIDGE | | d'ALBORA CABARITA | |
|-----------------------|---------|------------------|---------------|--------------------|---------------|-------------------|---------------|
| | | Vessels | % of Total | Vessels | % of Total | Vessels | % of Total |
| Sailing Vessels | Low | 32 | 17.11 | 6 | 12.00 | 14 | 11.29 |
| Cruisers - Sports | Low | 102 | 54.55 | 28 | 56.00 | 70 | 56.45 |
| Cruisers – Fly-bridge | High | 50 | 26.74 | 16 | 32.00 | 37 | 29.84 |
| Commercial Vessels | High | 3 | 1.60 | 0 | 0.00 | 3 | 2.42 |
| Total | | 187 | 100.00 | 50 | 100.00 | 124 | 100.00 |
| | | | | | | | |

It was noted that each of the three marinas have berths for vessels ranging from 8m to 25m in length. Photographs were taken at each marina. A photograph was also taken at the small Cape Cabarita residential marina for the purpose of recording the vessel profiles at that marina. The photographs are set out on the following pages.

7. ANTICIPATED BOAT TYPES & PROFILES (CONTINUED)

Photographs of Marinas Surveyed – June 2009:



BIRKENHEAD POINT MARINA



BIRKENHEAD POINT MARINA

7. ANTICIPATED BOAT PROFILES AND SIZES (CONTINUED)

Photographs of Marinas Surveyed – June 2009:



GLADESVILLE BRIDGE MARINA



GLADESVILLE BRIDGE MARINA

7. ANTICIPATED BOAT PROFILES AND SIZES (CONTINUED)

Photographs of Marinas Surveyed – June 2009:



d'ALBORA MARINA CABARITA



CAPE CABARITA RESIDENTIAL MARINA

7. ANTICIPATED BOAT PROFILES AND SIZES (CONTINUED)

Table S, at the beginning of this section, sets out a summary of the vessel types and profiles for those vessels surveyed at Birkenhead Point, Gladesville Bridge and d’Albora Cabarita Marinas in June 2009.

Whilst Table S shows that the ratios for other vessel types were fairly comparable, it is noted that there was a higher ratio of sailing vessels at Birkenhead Point Marina than was recorded at Gladesville Bridge and Cabarita Marinas.

This is very likely due to Birkenhead Point Marina being much closer to east Sydney Harbour where regular club sailing regattas are held. This marina is also nearer to Sydney Heads and the Tasman Sea for off-shore sailing and cruising. Yachts are generally only fitted with auxiliary engines and thus the speed at which a yacht can travel under power is relatively slow when compared to power vessels. Opposing currents in Parramatta River can extend the voyage time of a yacht by half as much again as compared to travelling with the currents. Thus, to some yacht owners, Birkenhead Point has some advantages.

For the purpose of estimating the mix of vessels and profiles anticipated to be berthing at the proposed Inner West Marina, the figures set out for each marina in Table S above have been consolidated into the following summary:-

**SUMMARY OF VESSEL PROFILES
BIRKENHEAD POINT, GLADESVILLE BRIDGE AND CABARITA MARINAS**

| VESSEL TYPE | PROFILE | TOTAL VESSELS | |
|-----------------------|---------|---------------|---------------|
| | | Vessels | % of Total |
| Sailing Vessels | Low | 52 | 14.41 |
| Cruisers - Sports | Low | 200 | 55.40 |
| Cruisers – Fly-bridge | High | 103 | 28.53 |
| Commercial Vessels | High | 6 | 1.66 |
| Total | | 361 | 100.00 |

Survey - Australian Marina Management Pty limited – June 2009

Taking into account the earlier observations about sailing vessels and proximity to east Sydney Harbour, using the above summary and Table S, the following mix of vessels is anticipated to make up the demand for berthing at Inner West Marina:-

| <u>VESSEL TYPE</u> | <u>PROFILE</u> | <u>% OF TOTAL</u> | <u>No OF VESSELS</u> |
|-----------------------|-----------------|-------------------|----------------------|
| Sailing Vessels | Low | 12% | 21 |
| Cruisers – Sports | Low | 57% | 98 |
| Cruisers – Fly-bridge | High | 31% | 53 |
| Commercial Vessels | Not Anticipated | -- | -- |

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7. ANTICIPATED BOAT PROFILES AND SIZES (CONTINUED)

The following photos are representative of some of the types of vessels which could be expected to berth at the proposed Inner West Marina.



Riviera 43' Offshore Express Cruiser



Riviera 47' Sports Cruiser



Mustang 28' Sports Cruiser



Mustang 38' Sports Cruiser



Riviera 56' Open Fly-bridge Cruiser



Riviera 47' Enclosed Fly-bridge Cruiser

7. ANTICIPATED BOAT PROFILES AND SIZES (CONTINUED)



Bayliner 32' Sports Cruiser



Dufour 52' Yacht

For the low profile sports cruiser vessels, the height above waterline (“bridge clearance”) is usually less than 3m for vessels up to 10m in length, less than 4m for vessels up to 13m in length and less than 5m for vessels up to 16m in length.

Fly-bridge cruisers have a higher profile for about one-third the length of the vessel. The heights above waterline for the larger fly-bridge cruisers would range from around 5.5m to around 6.5m.

8. SUMMARY AND CONCLUSIONS

Inner West Marina Sydney is a new marina facility proposed to be developed in Kendall Bay on the Parramatta River adjoining the waterside residential estate known as Breakfast Point.

The marina has been designed to provide modern floating berth storage for 172 vessels from 8m to 25m in length with safe, secure and structured access for community members including those with disabilities. Whilst the marina will not offer facilities for fuel or vessel repairs it will provide a sewage and waste water pump-out facility and car-parking.

On the site's former industrial coal loading wharf, it is also proposed to construct a new wharf bisecting the marina with a kiosk at its seaward end and a small building for marina management, with some amenities for marina patrons at its shore end.

Inner West Marina Sydney is planned to be operated as a commercial marina with berths made available to the wider community and not as a residential marina where berths are generally restricted to use by residents of dwellings within the residential estate.

Australian Marina Management Pty Limited has been commissioned by TLB Engineers Pty Limited to conduct a study to identify both current and anticipated future demand for marina berthing in Sydney and specifically at the proposed Inner West Marina Sydney and to comment upon the proposed berth size distribution as well as the profile of vessels which are most likely to make up the demand for berthing at Inner West Marina Sydney.

A survey of Sydney Harbour at June 2009 shows that there are presently sixty-eight (68) marina and boatshed facilities with a capacity of 2,186 berths. Thirty-eight (38) of these facilities are located west of Sydney Harbour Bridge with a capacity of 1,073 berths.

Of these 1,073 berths however, 371 berths are private residential berths not available to the wider community. This is 36.4% of marina berths in the west Sydney area. There are also 54 berths used by commercial charter vessels and which are also not available.

Thus in Sydney Harbour, west of the Sydney Harbour Bridge, there are only 584 berths spread over 12 commercial marinas and 64 berths spread over 10 commercial boatsheds.

Of the 584 berths at the 12 commercial marinas surveyed in June 2009, 550 berths, representing 94.2% of the total, were occupied thereby evidencing the high level of demand for marina berths in the west Sydney area.

Unlike the east of Sydney, there is not any sailing or boat club marinas in the west Sydney area.

8. SUMMARY AND CONCLUSIONS (CONTINUED)

The only commercial marinas west of Sydney Harbour Bridge with floating marina berths are Birkenhead Point Marina, Gladesville Bridge Marina and d’Albora Marina Cabarita. The remaining 9 marinas are aged fixed wharf-type berth structures and are therefore regarded as neither attractive nor safe by vessel owners seeking the modern marina facilities which are expected by today’s discerning society.

A survey of NSW Maritime private moorings in Sydney Harbour at June 2009 shows that 4,851 mooring licences have been issued again evidencing the high demand for on-water boat storage in Sydney Harbour.

The survey also notably shows that in addition to the 4,851 mooring licences issued there are a further 1,202 applications for mooring licences for Sydney Harbour on the NSW Maritime’s waiting lists. This represents 25% of issued licences and underlines the high level of demand referred to above.

The levels of mooring licences in Sydney Harbour have been limited for many years and, with indications that NSW Maritime has no plans to lift mooring numbers, there is no early prospect for applicants.

Moorings issued for waterways on the southern and northern shores, west of Sydney Harbour Bridge, total 2,512. Of these 2,512 licences, only 933 are located on the southern shores – some 640 moorings less than those issued for the northern shores.

For moorings west of Sydney Harbour Bridge there are a further 286 applications on NSW Maritime’s waiting list evidencing unfulfilled demand for on-water boat storage.

Of these 286 mooring applications, 193 (67%) are for moorings on the southern shores thereby demonstrating a strong and unsatisfied demand for on-water boat storage on the southern side of west Sydney Harbour.

The proposed Inner West Marina will be well positioned to satisfy some of this evident demand for 286 on-water vessel storage.

Commercial boatshed berth facilities at the 10 establishments west of Sydney Harbour Bridge are usually fully occupied with vessels being repaired and serviced. This in turn evidences further demand for on-water boat storage in Sydney Harbour at which vessels requiring repair and servicing can necessarily be accommodated.

Charter vessel berthing in Sydney generally is in short supply and thus the existing berth facilities are fully occupied mostly throughout the year.

8. SUMMARY AND CONCLUSIONS (CONTINUED)

West of Sydney Harbour Bridge there is eleven (11) private residential marinas with 371 berths. These berths are generally restricted to use by residents of the property and not available for use to meet the demand of the wider community.

Of the 371 berths at the residential marinas only 219 (59%) are occupied. Pulpit Point residential marina with 112 berths built in the late 1990s has had more than 60 vacant berths for 20 years or so. Due to other constraints there is no prospect for the unused berths at private residential marinas becoming available for use by the wider community.

The vessel registration data for the Sydney Harbour sector makes it clearly evident that the scarcity of marina berths in Sydney Harbour has acted as a heavy constraint to growth in boat ownership when compared to the total growth for the State.

The summary of vessel registrations in section 4.1 shows that for the 5-year period 2004 – 2009 the average annual growth for NSW was 2.67% pa whilst for the same period the average annual growth for the Sydney Harbour sector was a lower 1.17%pa.

The following summary shows the expected level of registered vessels at June 2009 for the Sydney Harbour sector by applying the NSW average annual growth rate of 2.67% to the Sydney Harbour sector 2004 base of 16,198 vessels.

| | |
|--|---------------|
| Registered Vessels - Sydney Harbour sector - June 2004 | 16,198 |
| Applying NSW 5-year growth 2004-2009 (13.33%) | <u>2,159</u> |
| Notional Registered Vessels – Sydney Harbour – June 2009 | 18,357 |
| Actual Registered Vessels – Sydney Harbour – June 2009 | <u>17,144</u> |
| Potential Latent Demand – Vessels | <u>1,213</u> |

From Table H in section 4.1 it is noted that of all NSW registered vessel 6.54% of these are 8m and above in length. Of the potential latent demand for ownership of 1,213 vessels in the Sydney Harbour sector it is therefore calculated that 6.54%, or approximately 80, of these vessels would be of a size requiring on-water storage.

In section 4.2 it is noted that, for the Sydney Harbour sector, there has been a small but consistent decline in the boat ownership ratio per 100 licences. This is in contrast to the ratio for NSW as a whole.

If the NSW ratio of vessel registrations per 100 licences at June 2009 (49.09) is applied to the June 2009 Sydney Harbour licences (41,129) then, at June 2009, the number of vessels registered for the Sydney Harbour area would be 20,190 (49.09 x 411.29). This is 3,046 vessels more than the 17,144 Sydney Harbour vessels actually registered at June 2009.

8. SUMMARY AND CONCLUSIONS (CONTINUED)

The 2009 figures have been influenced by the large abnormal increase in licences in the period. It would seem more prudent to use the end year 2008 data for such a comparison.

Thus, applying the total NSW ratio of registrations per 100 licences at June 2008 (51.35) to the 2008 Sydney Harbour licences (38,708), then, at June 2008, it is calculated that the number of vessels registered for Sydney Harbour would be 19,876 (51.35 x 387.08). This is 2,843 vessels more than the 17,043 vessels actually registered at June 2009.

These lower than total NSW ratios of boat ownership to licences indicate a likely strong latent demand in the Sydney Harbour area for boat ownership of all sizes of some 2,800 and 3,000 vessels.

Applying the 6.54% ratio of craft 8m and above in length to the calculated latent demand for boat ownership in Sydney Harbour of between 2,800 and 3,000 vessels, it is calculated that there is likely a latent demand in Sydney Harbour, at June 2009, for the ownership of between 183 and 196 additional vessels which would require marina berths.

The study clearly demonstrates there is actual and potential unfulfilled demand for on-water boat storage in Sydney Harbour as follows:

- Waiting lists for Sydney Harbour moorings (June 30)
Including 286 for west Sydney Harbour 1,202
- Calculated latent demand based on ratio of registered vessels per 100 licences 183

The proposed Inner West Marina will be able to satisfy some of the unfulfilled demand for on-water boat storage and will likely release some of the latent demand for boat ownership by persons refraining from purchasing a vessel due to the unavailability of modern marina facilities in Sydney Harbour.

Recreational vessel registration data within the study clearly evidences the continuing growth in ownership of larger vessels particularly for vessels of a length of 12m and above.

It is the owners of these vessels who will be seeking appropriate and suitable vessel on-water storage facilities thus increasing the strong demand for modern marina berths.

This of course has implications for marina planning and berth size distribution which needs to be done with at least a 30 year window to the future considering the improved and expected life of today’s modern marina systems and associated piling.

8. SUMMARY AND CONCLUSIONS (CONTINUED)

It is considered that the marina design and berth size distribution allows Inner West Marina management the flexibility to satisfy demands for boat owners well beyond the year 2040 thus avoiding the potential disruption and cost of reconfiguring the marina within its expected life.

The study has also considered the profiles of vessels likely to be berthing at the proposed Inner West Marina.

It is anticipated that around 120 of the 172 vessels will be low in profile such as yachts and sports cruisers shown in the photographs. Fly-bridge cruisers are not anticipated to exceed 50 or so in number of approximately 30% of the vessels at the marina.

In conclusion it is clear that demand for the proposed Inner West Marina Sydney at Kendall Bay will be extremely high.

This demand for berthing will be generated from the wider NSW sailing and boating community, not only from nearby residents on both sides of Parramatta River, but from residents of Sydney suburbs able to access Breakfast Point by road within 30 to 40 minutes.



APPENDIX 1

MARINA LAYOUT PLAN

TLB ENGINEERS

01013 DA03 REV E

APPENDIX 2
COMMERCIAL MARINAS - EAST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF MARINA</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|--|------------------------|----------------------|-------------------|---------------------|
| Rose Bay Marina | Rose Bay | 29 | 28 | 96.6 |
| Point Piper Marina | Rose Bay | 22 | 22 | 100.0 |
| Double Bay Marina | Double Bay | 40 | 38 | 95.0 |
| d'Albora Marina | Rushcutters Bay | 95 | 94 | 98.9 |
| Elizabeth Bay Marina | Elizabeth Bay | 9 | 7 | 77.8 |
| Neutral Bay Marina | Neutral Bay | 20 | 14 | 70.0 |
| Mosman Bay Marina | Mosman Bay | 35 | 30 | 85.7 |
| Short Marine (Fergusons) | The Spit | 33 | 33 | 100.0 |
| d'Albora Marina - Mosman | The Spit | 135 | 135 | 100.0 |
| Cammeray Marina | Long Bay | 22 | 22 | 100.0 |
| Northbridge Marina | Sailors Bay | 24 | 24 | 100.0 |
| Roseville Bridge Marina | Echo Point | 62 | 58 | 93.5 |
| Clontarf Marina | The Spit | 18 | 18 | 100.0 |
| Davis Marina | North Harbour | 30 | 27 | 90.0 |
| TOTAL FOR 14 COMMERCIAL MARINAS | | 574 | 550 | 95.8 |

COMMERCIAL MARINAS - WEST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF MARINA</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|--|------------------------|----------------------|-------------------|---------------------|
| Sydney Wharf 10 | Pymont Bay | 25 | 22 | 88.0 |
| Fish Markets Marina | Blackwattle Bay | 51 | 44 | 86.3 |
| Rozelle Superyacht Marina | Rozelle Bay | 24 | 24 | 100.0 |
| Balmain Marina | P'matta R. Balmain | 33 | 33 | 100.0 |
| Camerons Marina | P'matta R. Balmain | 16 | 15 | 93.8 |
| Birkenhead Point Marina | Iron Cove | 187 | 179 | 95.7 |
| Gladesville Bridge Marina | Five Dock Point | 50 | 48 | 96.0 |
| Cabarita Marina - Strata) | Hen & Chicken Bay | 72 | 68 | 94.4 |
| d'Albora Marina Cabarita) | | 52 | 49 | 94.2 |
| River Quays Marina | P'matta R. Mortlake | 23 | 23 | 100.0 |
| Woolwich Marina | P'matta R. Woolwich | 19 | 18 | 94.7 |
| Woodleys Marina | Berrys Bay | 32 | 27 | 84.4 |
| TOTAL FOR 12 COMMERCIAL MARINAS | | 584 | 550 | 94.2 |

Source: Sydney Harbour Boat Storage Survey – June 2009 – Australian Marina Management Pty Ltd

APPENDIX 3

SURVEY AT 30 JUNE 2009

CLUB MARINAS - EAST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF CLUB</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|----------------------------------|-----------------|---------------|------------|--------------|
| Royal Motor Yacht Club | Rose Bay | 106 | 105 | 99.1 |
| Cruising Yacht Club of Australia | Rushcutters Bay | 204 | 194 | 95.1 |
| Royal Sydney Yacht Squadron | Kirribilli | 11 | 10 | 90.9 |
| Middle Harbour Yacht Club | Parriwi Head | 75 | 72 | 96.0 |
| TOTAL FOR 4 CLUB MARINAS | | 396 | 381 | 96.2 |

CLUB MARINAS - WEST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF CLUB</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|--------------------------------|--------------------|---------------|------------|--------------|
| Drummoyne Sailing Club | P'matta R. D'moyne | 0 | 0 | |
| TOTAL FOR 1 CLUB MARINA | | 0 | 0 | |

SUMMARY

| | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|--|---------------|------------|--------------|
| CLUB MARINAS - EAST OF SYD. HARB. BRIDGE - 4 | 396 | 381 | 96.2 |
| CLUB MARINAS - WEST OF SYD. HARB. BRIDGE - 1 | 0 | 0 | 0.0 |
| TOTAL CLUB MARINAS SYDNEY HARBOUR - 5 | 396 | 381 | 96.2 |

Source: Sydney Harbour Boat Storage Survey – June 2009 – Australian Marina Management Pty Ltd

APPENDIX 4
RESIDENTIAL/PRIVATE MARINAS - EAST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF PROPERTY</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|--|-------------------|---------------|------------|--------------|
| Toff Monk Marina Trust | Elizabeth Bay | 11 | 5 | 45.5 |
| Woolloomooloo Wharf East | Woolloomooloo Bay | 34 | 30 | 88.2 |
| Woolloomooloo Wharf West | Woolloomooloo Bay | 44 | 26 | 59.1 |
| TOTAL FOR 3 RESIDENTIAL/PRIVATE MARINAS | | 89 | 61 | 68.5 |

RESIDENTIAL/PRIVATE MARINAS - WEST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF PROPERTY</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|---|----------------------|---------------|------------|--------------|
| Pier 6/7 Walsh Bay | Walsh Bay | 49 | 28 | 57.1 |
| Sydney Wharf 9 | Pymont Bay | 29 | 6 | 20.7 |
| Jones Bay Wharf | Jones Bay | 8 | 8 | 100.0 |
| Waterview Wharf Workshop | Mort Bay | 9 | 6 | 66.7 |
| Hopetoun Quays, Balmain | P'matta R. Balmain | 40 | 30 | 75.0 |
| Balmain Cove | Iron Cove | 31 | 25 | 80.6 |
| Abbotsford Cove | Abbotsford Bay | 13 | 12 | 92.3 |
| Cape Cabarita | France Bay | 23 | 18 | 78.3 |
| Hilly Street Mortlake | P'matta R. Mortlake | 16 | 10 | 62.5 |
| Pulpit Point | P'matta R. Pulpit Pt | 112 | 49 | 43.7 |
| Wondakiah, Wollstonecraft | Balls Head Bay | 41 | 27 | 65.9 |
| TOTAL FOR 11 RESIDENTIAL/PRIVATE MARINAS | | 371 | 219 | 59.0 |

SUMMARY

| | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|--|---------------|------------|--------------|
| RESIDENT'L MARINAS - EAST OF SYD HARB BDGE - 3 | 89 | 61 | 68.5 |
| RESIDENT'L MARINAS - WEST OF SYD HARB BDGE - 11 | 371 | 219 | 59.0 |
| TOTAL RESIDENTIAL MARINAS SYDNEY HARBOUR - 14 | 460 | 280 | 60.9 |

Source: Sydney Harbour Boat Storage Survey – June 2009 – Australian Marina Management Pty Ltd

APPENDIX 5

COMMERCIAL BOATSHEDS - EAST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF BOATSHED</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|--------------------------------|------------------------|----------------------|-------------------|---------------------|
| Pattons Slipway | Careening Cove | 4 | 3 | 75.0 |
| Balmoral Boatshed | Hunters Bay | 0 | 0 | 0.0 |
| Smiths Boatshed | The Spit | 24 | 20 | 83.3 |
| Lyons Boatshed | Willoughby Bay | 0 | 0 | 0.0 |
| Sailors Bay Boatshed | Sailors Bay | 0 | 0 | 0.0 |
| Castlecrag Boatshed | Mowbray Point | 12 | 10 | 83.3 |
| Manly Boatshed | North Harbour | 0 | 0 | 0.0 |
| TOTAL FOR 7 BOATSHEDS | | 40 | 33 | 82.5 |

COMMERCIAL BOATSHEDS - WEST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF BOATSHED</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|--------------------------------|------------------------|----------------------|-------------------|---------------------|
| Campbell Street Balmain | Mort Bay | 12 | 8 | 66.6 |
| Fountains Boatshed | Snails Bay | 12 | 12 | 100.0 |
| Cape Bouvard Marine | P'matta R. D'moyne | 4 | 4 | 100.0 |
| President Shipwright | P'matta R. D'moyne | 4 | 4 | 100.0 |
| Abbotsford Boatshed | P'matta Riv. Ab'ford | 0 | 0 | 0.0 |
| Waterview Rd Marine Centre | P'matta R. Putney | 10 | 10 | 100.0 |
| Woolwich Dock | Lane Cove R. W'wich | 8 | 3 | 37.5 |
| Stanard Marine | Berrys Bay | 14 | 12 | 85.7 |
| McMahons Point Boatshed | Lavender Bay | 0 | 0 | 0.0 |
| Lavender Bay Boatshed | Lavender Bay | 0 | 0 | 0.0 |
| TOTAL FOR 10 BOATSHEDS | | 64 | 53 | 82.8 |

SUMMARY

| | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|---|----------------------|-------------------|---------------------|
| BOATSHEDS - EAST OF SYDNEY HARBOUR BDGE - 7 | 40 | 33 | 82.5 |
| BOATSHEDS - WEST OF SYDNEY HARBOUR BDGE - 10 | 64 | 53 | 82.8 |
| TOTAL BOATSHEDS - SYDNEY HARBOUR - 17 | 104 | 86 | 82.7 |

Source: Sydney Harbour Boat Storage Survey – June 2009 – Australian Marina Management Pty Ltd

APPENDIX 6

CHARTER VESSEL BERTHING - EAST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF MARINA</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|---------------------------------------|------------------------|----------------------|-------------------|---------------------|
| Landseair | Careening Cove | 10 | 10 | 100.0 |
| Catalina Yachts | The Spit | 4 | 4 | 100.0 |
| TOTAL FOR 2 CHARTER FACILITIES | | 14 | 14 | 100.0 |

CHARTER VESSEL BERTHING - WEST OF SYDNEY HARBOUR BRIDGE

| <u>NAME OF MARINA</u> | <u>LOCATION</u> | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|---------------------------------------|------------------------|----------------------|-------------------|---------------------|
| King Street Wharf | Darling Harbour | 7 | 7 | 100.0 |
| Sydney Aquarium | Darling Harbour | 8 | 8 | 100.0 |
| Jones Bay Wharf | Jones Bay | 26 | 22 | 84.6 |
| Blackwattle Bay Wharves | Blackwattle Bay | 13 | 13 | 100.0 |
| TOTAL FOR 4 CHARTER FACILITIES | | 54 | 50 | 92.6 |

SUMMARY

| | <u>BERTHS</u> | <u>OCC</u> | <u>OCC %</u> |
|---|----------------------|-------------------|---------------------|
| FACILITIES - EAST OF SYDNEY HARBOUR BRIDGE - 2 | 14 | 14 | 100.0 |
| FACILITIES - WEST OF SYDNEY HARBOUR BRIDGE - 4 | 54 | 50 | 92.6 |
| TOTAL CHARTER MARINAS SYDNEY HARBOUR - 6 | 68 | 64 | 94.1 |

Source: Sydney Harbour Boat Storage Survey – June 2009 – Australian Marina Management Pty Ltd

APPENDIX 7

NSW MARITIME MOORING MAP

SYDNEY HARBOUR MOORINGS

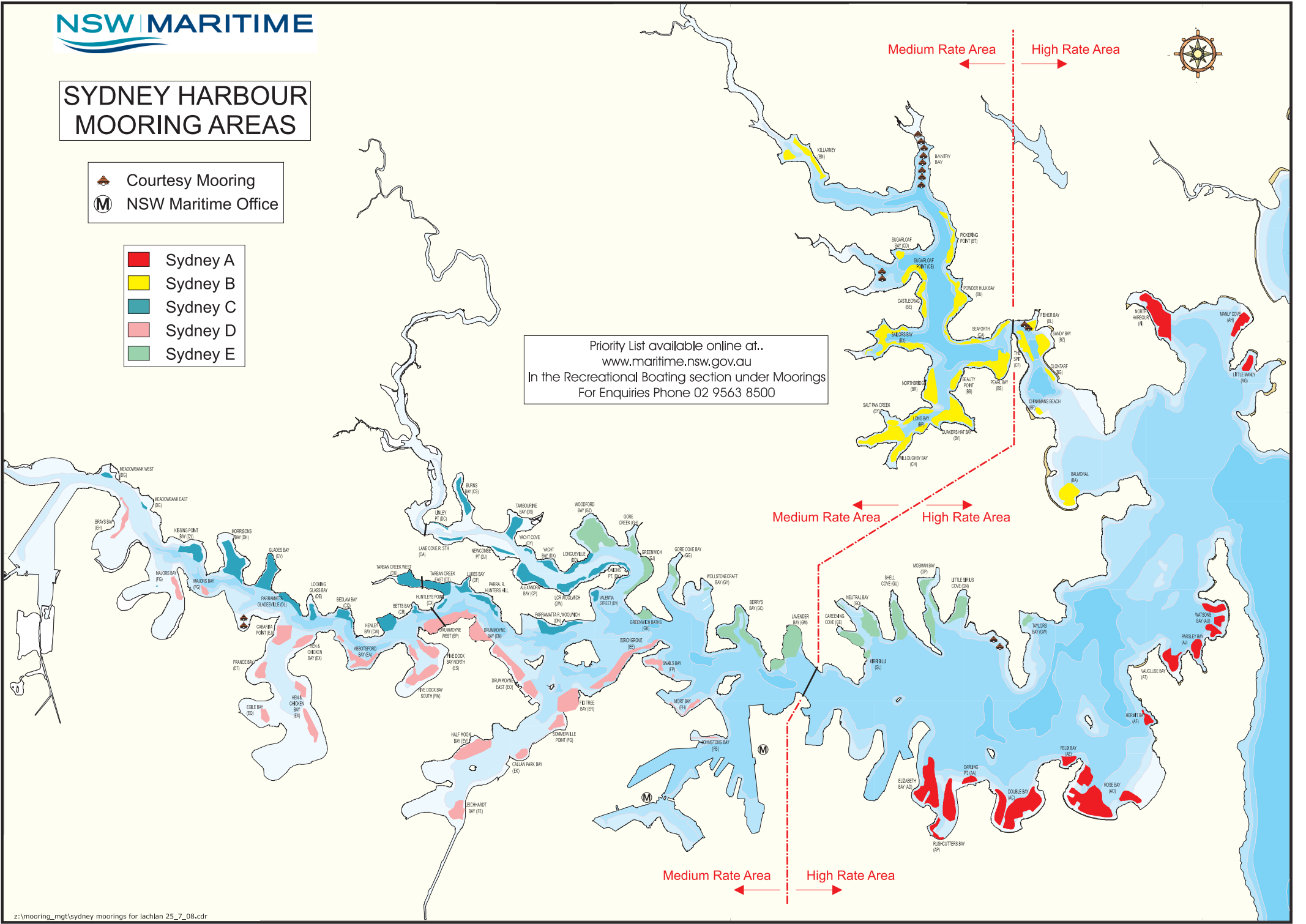
SYDNEY HARBOUR MOORING AREAS



-  Courtesy Mooring
-  NSW Maritime Office

- Sydney A
- Sydney B
- Sydney C
- Sydney D
- Sydney E

Priority List available online at..
www.maritime.nsw.gov.au
 In the Recreational Boating section under Moorings
 For Enquiries Phone 02 9563 8500



APPENDIX 12:
▪ **CONSTRUCTION
MANAGEMENT PLAN**



Construction Management Plan



Inner West Marina Sydney

TLB Project No: 01013
Status: Project Application to NSW Department of Planning
Date: 23rd October, 2009

Contents

1. Scope
2. Outline Construction Procedures
3. General Site Management
4. Traffic Management
5. Sedimentation and Erosion Control

Attachments

- Drawings CMP00, CMP01, CMP02, CMP03 and CMP04 prepared by TLB Engineers
- A copy of an article entitled: “Use of geotextiles to overcome challenging conditions at the seawall project in Port of Brisbane”
- Letter from Geofabrics Australia
- Article entitled “Chemical Aging Effects on the Physio-Mechanical Properties of Polyester and Polypropylene Geotextiles”
- Article entitled “Aging and Disability of Polyester Geotextiles”
- Details of Geotextile

1. Scope

This Construction Management Plan (CMP) has been prepared for Breakfast Point Pty Ltd for submission to the NSW Department of Planning as part of the Project Application for a new marina in Kendall Bay on the Parramatta River in Sydney.

This CMP is based on the drawings prepared by TLB Engineers DA01, DA02, DA03, DA04, DA05 and DA06.

This CMP should be read with reference to other expert reports relating to:

- i. The Environmental Management Plan – AECOM.
- ii. Noise Assessment – Heggies Pty Ltd.

This CMP should be read with reference to the attached drawings CMP00, CMP01, CMP02, CMP03 and CMP04.

2. Construction Procedures

2.1 Overview

This section describes an outline Construction Method. The selected contractor would prepare a detailed Construction Management Plan and detailed Environmental Management Plan to suit its specific construction procedures and programme.

The Contractor's Construction Management Plan would include vibration and noise control measures.

The Contractor's Construction Management Plan would be prepared with reference to:

1. "Do it Right on Site Soil and Water Management for the Construction Industry", published by the Southern Sydney Regional Organisation of Councils;
2. "Managing Urban Stormwater Soils and Construction", published by NSW Department of Housing (the Blue Book); and
3. "Dust Control – Do it Right on Site", published by the Southern Sydney Regional Organisation of Councils.
4. The report by Heggies Australia entitled "Inner West Marina, Kendall Bay Construction and Operation Noise Assessment".
5. The Environmental Management Plan by AECOM entitled "Construction Environmental Management Plan".

2.2 Work Areas

The work would be undertaken in two areas.

1. The landside area of the proposed car park on Peninsula Drive.
2. The waterside area in Kendall Bay.

The waterside works would be undertaken in stages. The final stage break up will be determined by the Contractor, nonetheless for the purpose of this Project Application we envisage that the waterside works being undertaken in 6 stages.

| | |
|---------|---|
| Stage 1 | Blanket Construction |
| Stage 2 | Fixed Jetty including Kiosk and Managers Office |
| Stage 3 | Floating Structure – Arms 4, 5, 6, 7 and 8 |
| Stage 4 | Floating Structure – Arm 3 |
| Stage 5 | Floating Structure – Arms 1 and 2 |
| Stage 6 | Pontoon and Ramp |

The works for the car park are independent of the other works. However it is envisaged that the car park would be constructed at the same time as the blanket to provide car parking for contractor personnel during construction of the Stages 2 to 6 of the works.

2.3 Structures

The various elements of the works would be constructed using the following materials:

1. **Car park** – asphaltic concrete over compacted base with concrete kerbs and landscaping.
2. **Blanket** – geotextile over which is placed basalt gravel/grade rock. The basalt will be tested for suitability before being approved for delivery to site. The blanket has a design life of greater than 100 years (refer to attached letter from Geofabrics Australia and attached papers on the durability of geotextiles).
3. **Floating Structure** – concrete piles and a proprietary modular pontoon system.
4. **Fixed Jetty** – steel piles with HDPE Sleeves supporting steel headstocks on which would be timber beams supporting timber decking.

All materials and equipment for the construction of the waterside works would be brought to site by barge.

2.4 Work Method

Car Park

The carpark would be constructed using standard equipment and work methods involving:

1. Removing existing ground to required levels.
2. Placement and compaction of base course material.
3. Placement and compaction of asphalt.
4. Concrete supply for kerbs using standard concrete trucks discharging the concrete directly into kerb forms.

Blanket

The blanket would be constructed using barge mounted equipment, including rolls of the geotextile and an excavator.

The geotextile would be laid continuously over the western side of the barge as it is moved slowly from west to east, commencing at the western side at high tide.

The geotextile would be laid in continuous sheets (pre made off site) of the order of 40m x 100m in plan area. Adjacent sheets of geotextile would be overlapped on the bed.

The initial section of each sheet would be placed by divers.

As the geotextile sheets are laid on the bed, the basalt rock gravel would be placed on the geotextile using the excavator with GPS controlled bucket.

The barges used for the placement of the geotextile and ballast would be secured with mooring lines to temporary piles. Winches on the barges would accurately position and move the barges along each east west run of blanket placement.

This construction method has been used successfully for the placement of a geotextile and basalt rock in the Port of Brisbane (a copy of an article about this project is attached).

As the work proceeds, geotextile rolls and ballast would be brought to site on "dumb" barges which would moor against the placement barge. As required, materials would be transferred from the "dumb" barges to the placement barge.

All work would be undertaken with two silt curtains in place; an outer curtain left in position around the whole of the site and an inner silt curtain which would progressively move south with the completion of each east west run of blanket construction.

The outer silt curtain would be moored to temporary piles. The inner curtain would be initially moored to the temporary piles, then as it moves with the area of construction activity, the inner silt curtain would be moored using mooring blocks placed on top of the newly constructed blanket.

The placement of the geotextile and basalt will be coordinated with ferry movements. As is required by NSW Maritime, ferries will slow to 4 knots when within 100m of a work barge.

Barge mooring lines will be kept taut to minimise the barge movements as a result of vessel wave effects. The lines will be adjusted as the tidal water level changes.

Piles

Piles would be installed after the placement of the blanket.

Each pile would be fitted with a purpose made shoe capable of cutting the geotextile when driven.

The piles would be located by GPS, positioned over the blanket. Divers will cut slits in the blanket at the pile location, then the pile will be driven through the blanket. On

completion of driving each pile, a geotextile collar will be placed over the pile. The collar will overlap with the geotextile blanket.

The piles would be placed through the pile guide brackets attached to the floating structure.

Floating Structure

The floating structure would be assembled in segments off site, and towed to site as required to suit the construction programme.

Once the first segment has been secured by two piles, further segments could be brought to site and temporarily moored against the previously installed segments, awaiting final positioning.

Fixed Structure

The piles for the fixed structure would be installed as described above.

Once the piles on each line have been installed, the HDPE jacket would be placed over the pile then the steel headstock inserted into the pile and secured into position.

Progressively as the headstocks are installed the timber beams between the headstocks, would be placed by a barge mounted crane, then the timber decking placed over the timber beams.

Mooring of Barges

Barges would be moored using mooring lines to piles.

It is envisaged that initially up to four temporary piles would be installed to secure and assist in the positioning of the barges for the installation of piles.

As piles are progressively installed the barges could use the piles for mooring points.

Mooring blocks on the bed of the bay would not be used.

Throughout the construction:

1. Limited materials would be stored on site.
2. Barge mounted cranes would be used for materials handling.
3. Contractor personnel vehicles would temporarily park on the street near the site until such time as the carpark is completed. Then these cars would park in the carpark.

Indicative On-Site Construction Periods

The construction period depends on the selected contractor's work sequence and construction method.

In order that there is some understanding of the periods for onsite construction of the works, the following indicative construction periods are noted:

| | | |
|----------------|---|-------------------------|
| Stage 1 | i) Car Park | 8 weeks |
| | ii) Blanket | 30 weeks |
| Stage 2 | Fixed Jetty including Kiosk and Managers Office | 24 weeks ⁽¹⁾ |
| Stage 3 | Floating Structures, including piles, for Arms 4, 5, 6, 7 and 8 | 14 weeks ⁽¹⁾ |
| Stage 4 | Floating Structures, including piles, for Arm 3 | 10 weeks |
| Stage 5 | Floating structures, including piles, for Arms 1 and 2 | 18 weeks |
| Stage 6 | Pontoon | 2 weeks |

⁽¹⁾ Could be undertaken concurrently.

Piles would be installed at the average rate of 2 per day.

There are approximately 160 piles required for the proposed works.

Working Hours

The work hours each day would be in accordance with the Canada Bay Council requirements and the Conditions of Consent, namely:

| | |
|------------------|--------------------|
| Monday to Friday | 7:00 am to 6.00 pm |
| Saturday | 8.00 am to 1:00 pm |
| Sunday | No work |

In order to reduce the level of “noisy” activities the work would be undertaken in accordance with the report prepared by Heggies Pty Ltd, “Inner West Marina, Kendall Bay Construction and Operation Noise Assessment”. In this report the installation of piles is recommended to commence no earlier than 8.00 a.m.

3. General Site Management

3.1 Carpark Works

Site Layout

The carpark site is located in the Breakfast Point Precinct and is bounded by Peninsular Drive and Rosewater Circuit. The site is adjacent to a residential building named ‘Stilkstone’.

For all site amenities temporary buildings will be located within the site boundaries at all times. The location, type and number of the site amenities will be determined closer to the commencement of construction.

Hoardings and Protection

Site Boundaries

Prior to the commencement of any construction works, a temporary perimeter fence will be constructed along the boundary lines. The fence will consist of 50mm chain wire mesh panels 2.1m high with hinged lockable gates that open inwards at all required access points. The fence will also be lined internally with shade cloth to help prevent dust and debris exiting the site from the construction activities.

Upon completion of each stage, the temporary chain wire fence will be removed.

Materials Handling

Excavation and Site Levelling

During the excavation works, trucks will be loaded within the site boundaries. Trucks would enter via Gate 1 and exit via Gate 2. The trucks will pass over the construction vehicle exit, at which point the trucks would be washed down to remove soil and debris.

Standing Trucks

Unloading of all materials and equipment will be carried out on site whenever possible. If any on-street standing is required (including from the carriage way, footpath or verge), all activities will be supervised at all times by qualified traffic controllers.

Machinery

An all terrain telescopic handler (or similar) will be on site for the construction phase of the project for on site materials handling. This machine will be approximately 2-5 tonne capacity and will only be operated by qualified personnel. Various other types and sizes of machinery will also be on site throughout different phases of the project. These include, but are not limited to, excavators, backhoes, rollers, asphalt laying vehicles, forklifts, and concrete pumps.

Site Storage

Construction materials and waste containers for construction refuse will be stored within the site in an area not accessible to the public. The location for storage of the items will vary throughout construction due to changing site constraints. Dedicated storage areas will be established by way of the placement of lockable storage containers and installation of temporary fencing. No materials will be stored outside of the site boundary.

All stored material locations are to be co-ordinated with the site foreman.

Tree Protection

All trees adjacent to site that are nominated as being retained are to be protected at all stages throughout construction. In order to achieve this, temporary 1.8m high chainwire fences are to be constructed around each tree, or cluster of trees, and will encompass the primary root zones where practicable. Any works to be carried out

close to the trees nominated to be retained will be supervised by an experienced and qualified Arborist.

Waste Management

Construction Waste

Rubbish skips/bins will be used during the course of the project for the collection of general construction waste and material packaging. Rubbish skips will be located within the site.

All rubbish placed in skips will be removed from site by a waste collection company and taken to an approved or licensed waste disposal and recycling facilities. At no time will rubbish skips/bins be stored on the footpath or roadway during the course of construction.

Excavated Materials

Excavated material will be tested for contaminants and placed in sealed trucks for transport to the appropriate landfill site.

Where necessary, and in accordance with a Site Remediation Action Plan, contaminated material would be stockpiled on site, dewatered and the material and water treated before the material is loaded onto trucks.

Water would be treated in accordance with an Environmental Management Plan.

Material stock piles will be sprayed with water from time to time to keep dust down and if necessary covered.

Perishable Waste

Perishable wastes will be stored on site in appropriate receptacles with lids to minimise vermin attraction.

3.2 Waterside Works

Site Layout

The area for the waterside works is adjacent to the foreshore public access zone on the western side of the site. Approximately 250m east of the mean high water mark, and approximately 90m east of the site, is the vessel access path of Sydney Ferries vessels moving to and from Cabarita Ferry Wharf.

All waterside works will be undertaken using plant and equipment mounted on barges. All amenities for the construction personnel will be on the barges.

Materials Handling

All materials for waterside works will be delivered to site on barges which will be securely moored to piles.

Materials will be handled using the barge mounted equipment.

All materials will be secured to the barges until required for installation.

Construction Waste

All construction waste will be placed in sealed bins on the barges. These bins will be covered.

From time to time the bins will be removed from site and the waste taken to an approved landfill or waste processing facility.

4. Traffic Management

4.1 Carpark Works

Heavy Vehicle Access Routes

Heavy vehicle access to the site would be along Tennyson Road, and, into Magnolia Drive and Rosewater Circuit within the Breakfast Point Precinct.

Vehicles would turn onto the site at the southern side (Gate 1) and depart from the site via Gate 2, turning left onto Rosewater Circuit.

From time to time vehicles will park on Rosewater Circuit and Peninsular Drive in the two construction zone parking areas marked on the drawings TPA1 and TPA2 until they are able to move onto the site.

Heavy Vehicle Movements

It is estimated that the following movement of heavy vehicles would be indicative for the carpark construction works:

1. During site preparation and removal of ground – 50 total movements over three days with a peak of three movements per hour;
2. Concrete supply – 20 trucks over two days with a peak of two trucks per hour;
3. Asphalt supply – ten trucks over two days with a peak of one truck per hour.

Vehicle Access

Vehicle access is to be via Gate 1 as described for Heavy Vehicle access and egress. All access gates will be sign posted and all vehicles are to enter and leave the site in a forward direction wherever possible.

Vehicle Parking

Construction workers' vehicles will not be allowed to be parked on the Breakfast Point streets parking areas. The parking of construction workers vehicles will be managed under the contractor Construction Management Plan.

Throughout all phases of construction, workers will be encouraged to car pool and utilise public transport. Site personnel will continually monitor parking and ensure the disturbance so surrounding residents is minimal.

Pedestrian Management

As a safety provision for pedestrians, movement past site entries may be restricted during construction activities. Safety and directional signs will be provided during these periods. The footpaths around the site will remain unobstructed at all times.

Access

Pedestrians and personnel to enter the sites will do so via the designated access gates as described for Heavy Vehicle access and egress. Unauthorised entry to work site is prohibited, and signage will be in place to inform pedestrians of access restrictions and requirements. Directional signage will also be in place to direct all personnel and visitors to the site office.

4.2 Waterside Works

Vessel Access

All vessel access to the site would be from the north. Vessels would travel along the main channel of the Parramatta River until reaching the Headland/Point known as Breakfast Point, then turn south to the site.

Vessels would approach the site on a path between 100m and 190m east of the foreshore mean high water mark. This is 60m clear of the ferry access path.

Navigation Management

In order that the construction activities have minimal effect on Sydney Ferries operations and that construction activities including vessel access do not stray into the navigable water used by Sydney Ferries, temporary buoys would be placed east of the site and west of the Sydney Ferries vessel path. These buoys are shown on drawing CMP00 and marked TCB1 to TCB5 inclusive.

The buoy marked TCB5 would identify the southern extent of the construction zone. No vessel movements or other activities would be permitted south of this buoy.

5. Sedimentation and Erosion Control

This plan identifies sediment control systems to be implemented on all stages of the project. The sediment control systems are designed to minimise erosion on site and retain sediment eroded by water and wind and minimise the risk of disturbed sediment leaving the site area.

The details for the Environment Management are set out in the plan prepared by AECOM.

Erosion and Sediment Control Devices

Two floating silt curtains and booms will be placed around each stage of the waterside works, including the areas for the blanket.

The mooring and movement of the silt curtains as the work proceeds is set out in section 2.4 – Blanket, of this CMP.

Silt fences and erosion control measures will be placed around the site for the car park (refer to drawing CMP04).

The erosion and sediment control devices described below will be in place throughout all construction. Any collected silt will be disposed of in accordance with Council's Erosion and Sediment Control policies, any other relevant codes or standards, and the EMP for the project.

Silt Fences

Silt fences are to be installed around the site for the car park as part of the site fence. Geotextile fabric will be fixed to the temporary construction fencing as can be achieved. The fabric will be turned down under the existing ground line and secured at regular intervals not exceeding 3m.

Vehicle Access

During car park construction vehicular access will be controlled to prevent sediment being tracked onto the adjoining roads. This will be done by maintaining an all weather access/driveway to each stage composed of an approved course aggregate surface. Also if the need arises, a shaker grid will be installed to the exit gate. The shaker grid combined with the gravel driveway will reduce/eliminate tracking of soil and mud onto the surrounding roads. Any sediment that is tracked onto the surrounding roads will be cleaned off in a timely manner.

Stormwater Inlets

During car park construction all stormwater inlets near the site will have protection installed to prevent soil and other materials from entering. This will consist of 50-70mm gravel inside geo-textile and netting placed at the storm water inlets. These will be referred to as filter bags. The filter bags will not only be placed directly at the inlets as shown below, they will also be placed at regular intervals in the gutters 'upstream' from the inlets creating multiple barriers.

Stockpiles

If stockpiling is required, stockpiles shall be stored at least 2m clear of drainage lines and easements, natural watercourse, footpath, kerb, road surface, and established trees. Stockpiles will have temporary silt fences in place around the stockpiles to create an enclosure and if necessary they will be covered with shade cloth or tarpaulin to retain the materials on the stockpile. The location of stockpiles will be determined as construction progresses.

Waste and Contaminated Material Enclosures

As necessary and in accordance with the EMP, during the excavation waste enclosures will be set up on site for the treatment of contaminated material.

Contaminated solid material would be placed in sealed bins as necessary and transported to an approved disposal site.

Dust Control

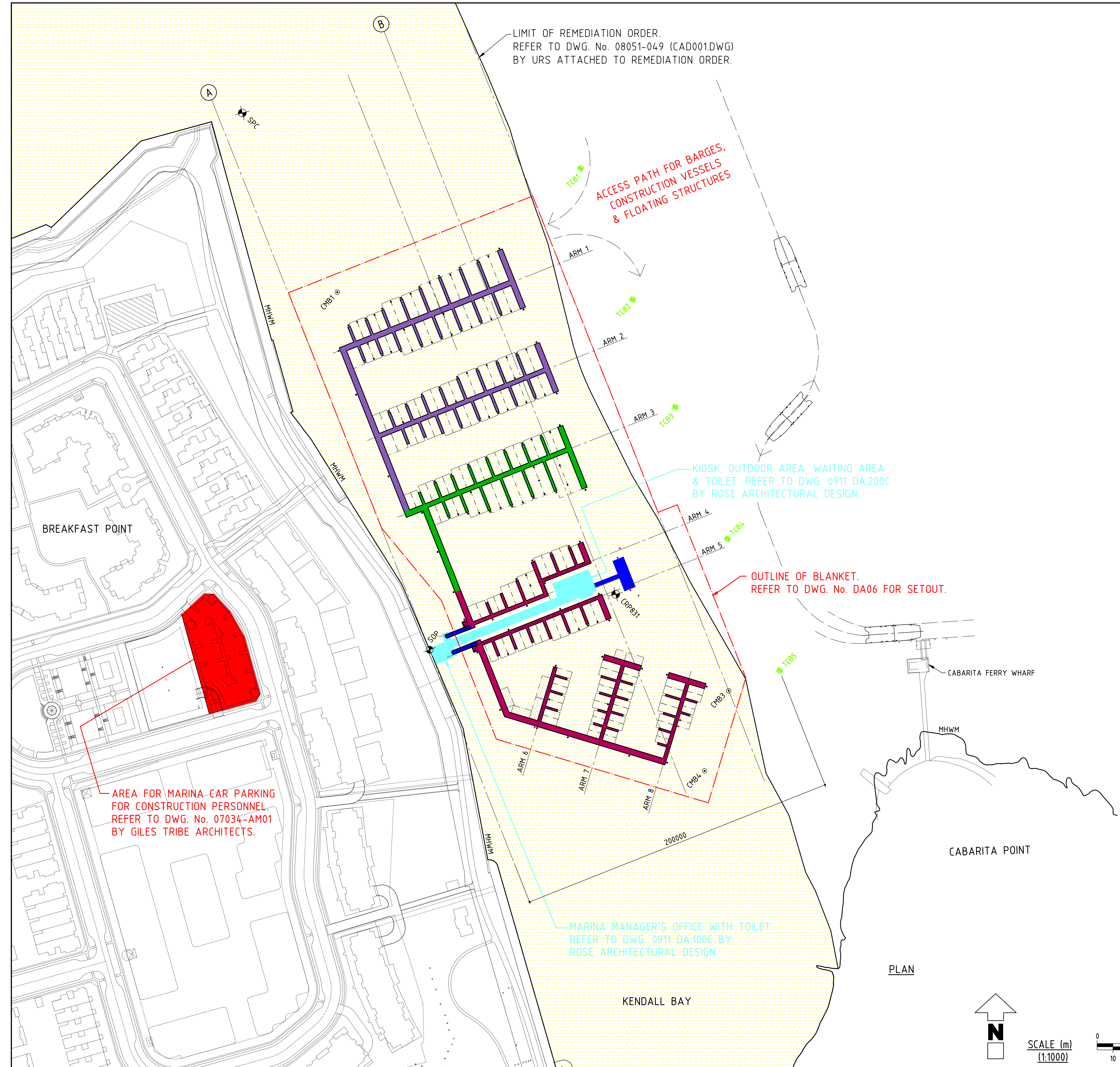
During car park construction the shade cloth to the boundary fences will be maintained throughout all stages of construction to assist in dust control. Also if the need arises due to excessive dust being created, the site will be watered down by a water truck where possible, and/or sprinklers and hoses. Also all stockpiled soils will be covered during periods of high wind to reduce the dust created from on site storage.

Monitoring

In order to maintain the various erosion and sediment control devices, regular inspections, repairs and cleaning will be carried out on the silt fences to the boundaries, stockpiles, waste enclosures, to the stormwater inlet filter bags and to the stockpile covers. Inspections of the site erosion and sediment control devices will generally be done on a weekly basis, however if the need arises inspections will be done at closer intervals.

APPENDIX 12:

- **DRAWINGS CMP00,
CMP01, CMP02, CMP03
AND CMP04**



LIMIT OF REMEDIATION ORDER.
REFER TO DWG. No. 08051-049 (CAD001.DWG)
BY URS ATTACHED TO REMEDIATION ORDER.

ACCESS PATH FOR BARGES,
CONSTRUCTION VESSELS
& FLOATING STRUCTURES

KIOSK, OUTDOOR AREA, WAITING AREA
& TOILET. REFER TO DWG. 0911 DA.200C
BY ROSE ARCHITECTURAL DESIGN.

OUTLINE OF BLANKET.
REFER TO DWG. No. DA06 FOR SETOUT.

MARINA MANAGER'S OFFICE WITH TOILET
REFER TO DWG. 0911 DA.100C BY
ROSE ARCHITECTURAL DESIGN.

AREA FOR MARINA CAR PARKING
FOR CONSTRUCTION PERSONNEL
REFER TO DWG. No. 07034-AM01
BY GILES TRIBE ARCHITECTS.

LEGEND :

- CMB1 - CMB4 : CHANNEL MARKER BUOY.
- ⊕ CRP831 : EXISTING MARKER BUOY.
- ⊕ SOP : SET OUT POINT.
- ⊕ SPC : EXISTING CHANNEL MARKER PILE.
- ⊕ TCB1 - TCB5 : TEMPORARY CONSTRUCTION BUOYS.
REFER TO MGA94 (ZONE 56) CO-ORDINATES

| MARK | MGA94 (ZONE 56) CO-ORDINATES (TO BE USED FOR FINAL SETOUT) | |
|--------|---|--------------|
| | EASTING (m) | NORTHING (m) |
| CRP831 | 325535.00 | 6253927.00 |
| SPC | 325300.00 | 6254230.00 |
| SOP | 325417.91 | 6253892.06 |
| TCB1 | 325513.63 | 6254099.82 |
| TCB2 | 325540.45 | 6254032.14 |
| TCB3 | 325573.30 | 6253949.23 |

- █ STAGE 1 - CONSTRUCT BLANKET & CARPARKING AREA
- █ STAGE 2 - CONSTRUCT FIXED JETTY
- █ STAGE 3 - FLOATING STRUCTURE & PILES
- █ STAGE 4 - FLOATING STRUCTURE & PILES
- █ STAGE 5 - FLOATING STRUCTURE & PILES
- █ STAGE 6 - PONTOON & RAMP

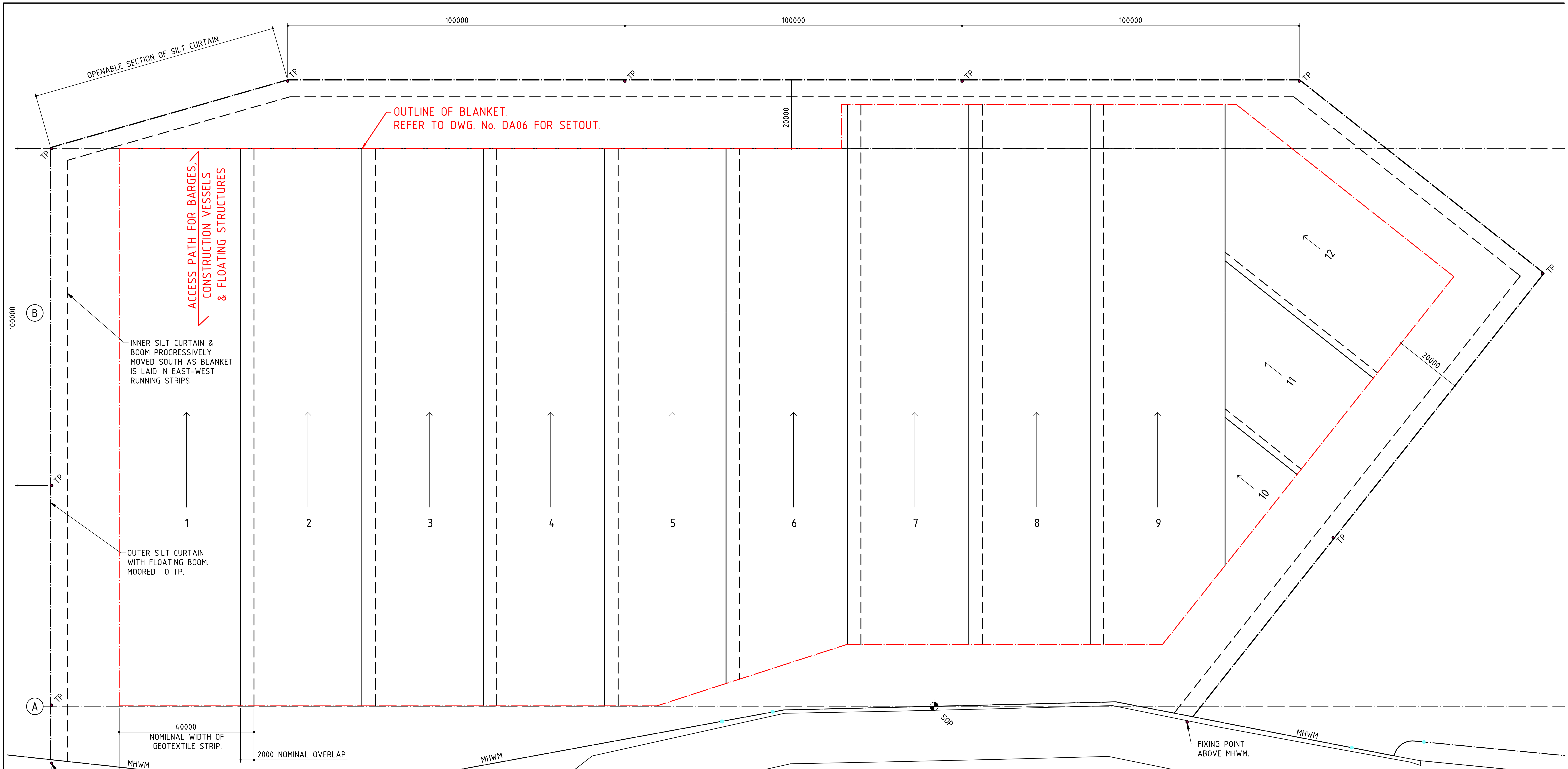
- 04 : PROJECT APPLICATION 09.10.09
- 03 : LIMIT OF REMEDIATION ORDER ADDED 04.09.09
- 02 : PROJECT APPLICATION 14.07.09
- 01 : PROJECT APPLICATION 09.07.09



CONSTRUCTION STAGING

Design H.B. Scales 1:1000 Job No. 01013
 Drawn S.K. Date 28.05.09 Dwg. No. CMP00
 App'd. Sheet Size B1 Rev. No. 04





OUTLINE OF BLANKET.
REFER TO DWG. No. DA06 FOR SETOUT.

ACCESS PATH FOR BARGES,
CONSTRUCTION VESSELS
& FLOATING STRUCTURES

INNER SILT CURTAIN &
BOOM PROGRESSIVELY
MOVED SOUTH AS BLANKET
IS LAID IN EAST-WEST
RUNNING STRIPS.

OUTER SILT CURTAIN
WITH FLOATING BOOM.
MOORED TO TP.

PLAN ON STAGE 1 - BLANKET CONSTRUCTION

- TP : TEMPORARY PILE TO SUPPORT SILT CURTAIN AND FOR BARGE MOORING LINE ATTACHMENT.
- ↑ : DIRECTION FOR PLACEMENT OF GEOTEXTILE AND BALLAST.
- 1 : ORDER FOR PLACEMENT OF GEOTEXTILE AND BALLAST.

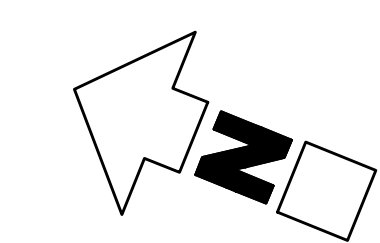
NOTE: MOORING OF INNER SILT CURTAIN INITIALLY MOORED TO TP. AS SILT CURTAIN IS MOVED SOUTH IT WOULD BE MOORED USING ANCHOR BLOCKS ON TOP OF THE NEWLY PLACED BLANKET.

| | |
|--------------------------|----------|
| 03 : PROJECT APPLICATION | 09.10.09 |
| 02 : PROJECT APPLICATION | 14.07.09 |
| 01 : PROJECT APPLICATION | 09.07.09 |

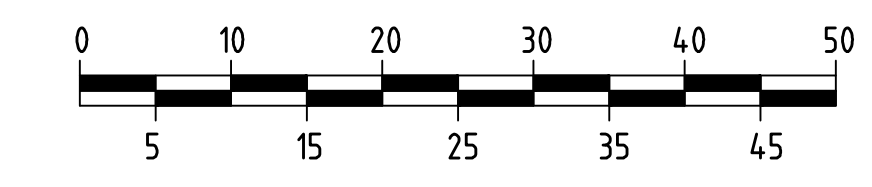


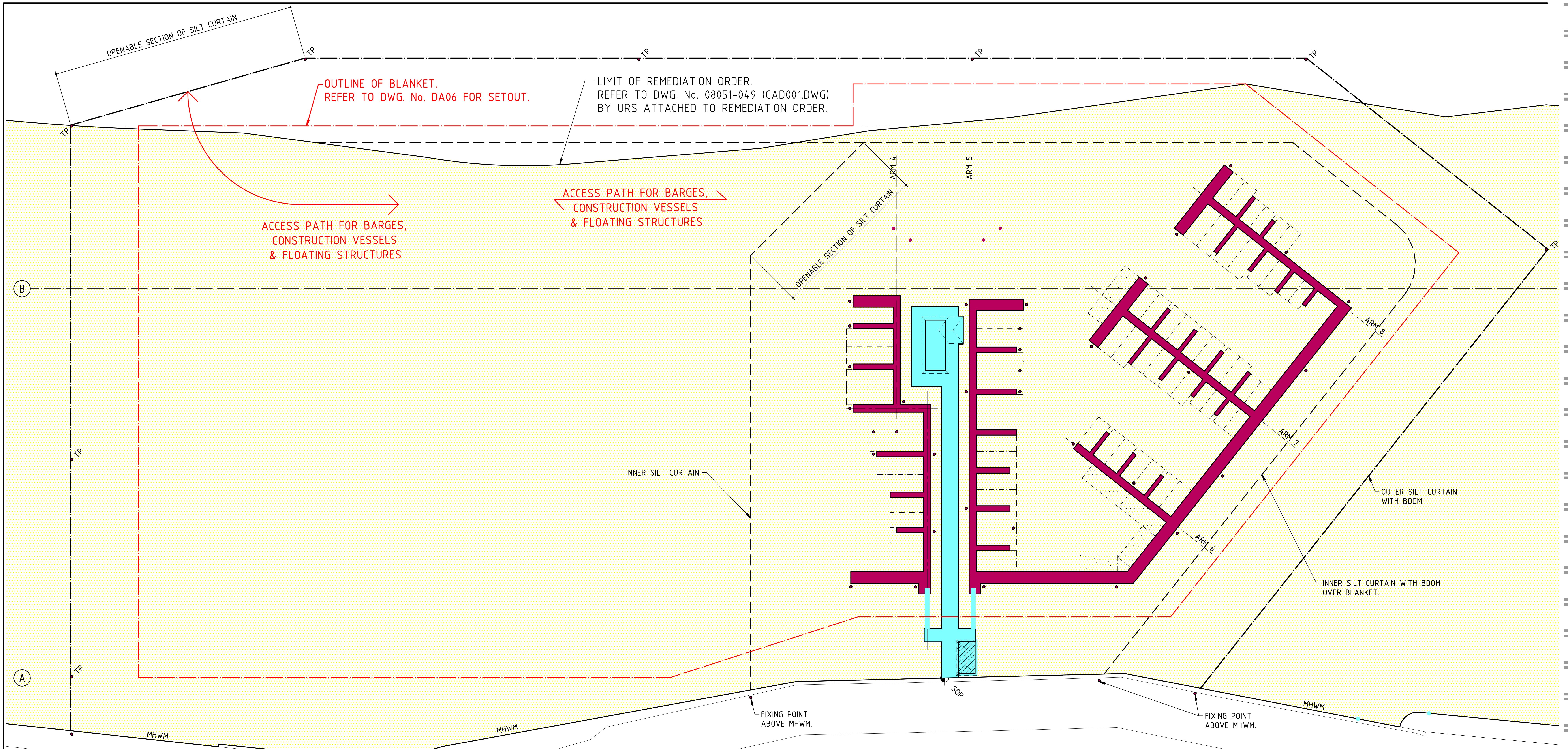
CONSTRUCTION STAGING

| | | |
|-------------|---------------|----------------|
| Design H.B. | Scales 1:500 | Job No. 01013 |
| Drawn S.K. | Date 29.05.09 | Dwg. No. CMP01 |
| App'd. | Sheet Size B1 | Rev. No. 03 |



SCALE (m)
(1:500)





PLAN ON STAGES 2 & 3

STAGE 1 - CONSTRUCT BLANKET & CARPARKING AREA

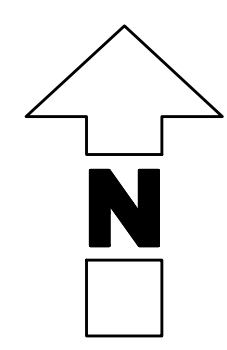
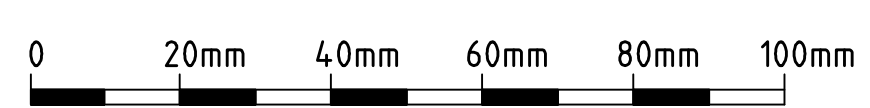
STAGE 2 - CONSTRUCT FIXED JETTY

| | |
|---------------------------------------|----------|
| 04 : PROJECT APPLICATION | 09.10.09 |
| 03 : LIMIT OF REMEDIATION ORDER ADDED | 04.09.09 |
| 02 : PROJECT APPLICATION | 14.07.09 |
| 01 : PROJECT APPLICATION | 09.07.09 |

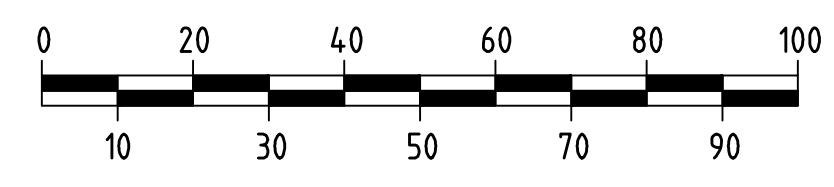


CONSTRUCTION STAGING

| | | |
|-------------|---------------|----------------|
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| Drawn S.K. | Date 29.05.09 | Dwg. No. CMP02 |
| App'd. | Sheet Size B1 | Rev. No. 04 |



SCALE (m)
(1:1000)



OPENABLE SECTION OF SILT CURTAIN

OUTLINE OF BLANKET.
REFER TO DWG. No. DA06 FOR SETOUT.

LIMIT OF REMEDIATION ORDER.
REFER TO DWG. No. 08051-049 (CAD001.DWG)
BY URS ATTACHED TO REMEDIATION ORDER.

ACCESS PATH FOR BARGES,
CONSTRUCTION VESSELS
& FLOATING STRUCTURES

(B)

(A)

OUTER SILT CURTAIN WITH
FLOATING BOOM.

INNER SILT CURTAIN.

FIXING POINT
ABOVE MHWM.

FIXING POINT
ABOVE MHWM.

FIXING POINT
ABOVE MHWM.

MHWM

MHWM

SOP

PLAN ON STAGES 4 & 5

■ STAGE 4 - FLOATING STRUCTURE & PILES

■ STAGE 5 - FLOATING STRUCTURE & PILES

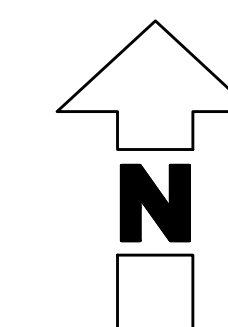
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|---------------------------------------|----------|
| 04 : PROJECT APPLICATION | 09.10.09 |
| 03 : LIMIT OF REMEDIATION ORDER ADDED | 04.09.09 |
| 02 : PROJECT APPLICATION | 14.07.09 |
| 01 : PROJECT APPLICATION | 09.07.09 |



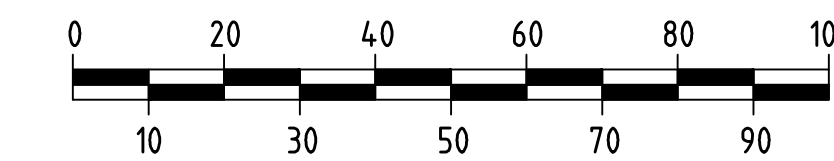
CONSTRUCTION STAGING

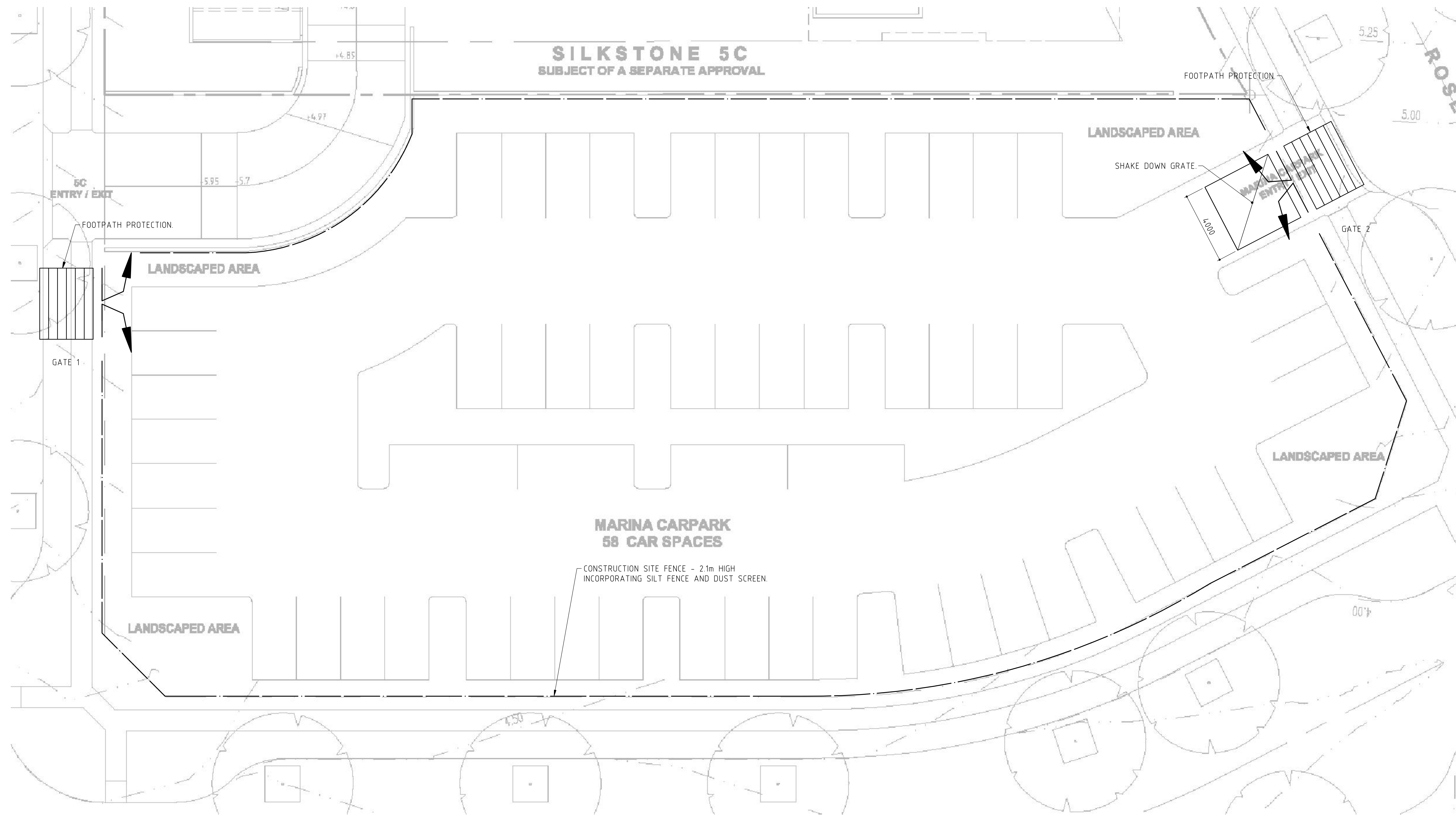
| | | |
|-------------|---------------|----------------|
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| Drawn S.K. | Date 29.05.09 | Dwg. No. CMP03 |
| App'd. | Sheet Size B1 | Rev. No. 04 |

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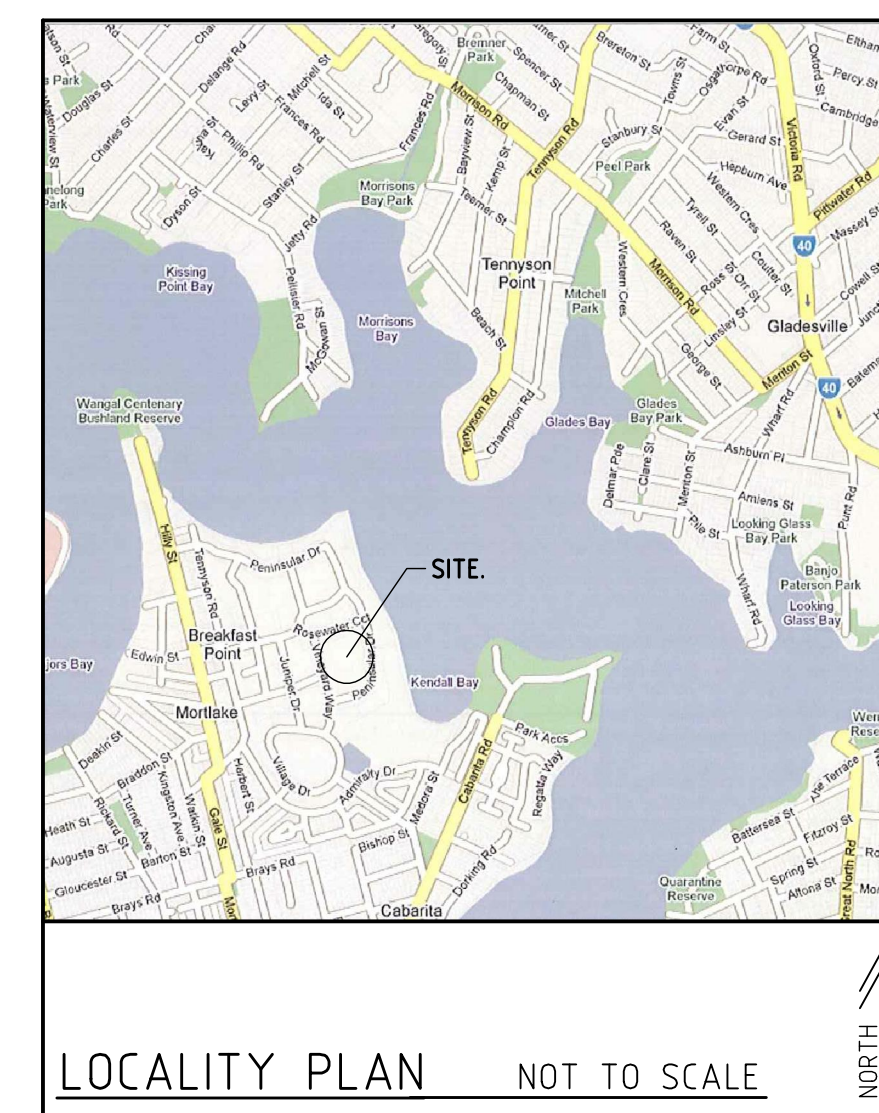
SCALE (m)
(1:1000)





PLAN ON CARPARK

| LEGEND | |
|--------|---------------------------|
| | SITE GATES |
| | SITE VEHICULAR ENTRY/EXIT |
| | |
| | |



01 : PROJECT APPLICATION 09.07.09



CONSTRUCTION STAGING

| | | |
|-------------|---------------|--------------|
| Design H.B. | Scales 1:100 | Job No 01013 |
| Drawn S.K. | Date 05.06.09 | Dwg No CMP04 |
| App'd | Sheet Size B1 | Rev. No 01 |



0 20mm 40mm 60mm 80mm 100mm

APPENDIX 12:

- **GEOTEXTILE INFORMATION**
ARTICLE ENTITLED: “USE OF
GEOTEXTILES TO OVERCOME
CHALLENGING CONDITIONS AT
SEAWALL PROJECT IN PORT OF
BRISBANE”

Use of geotextiles to overcome challenging conditions at the seawall project in Port of Brisbane

Ameratunga, J.

Coffey Geosciences Pty Ltd, Brisbane, Australia. ameratunga@coffey.com.au

Boyle, P.J.

Port of Brisbane Corporation, Brisbane, Australia. Peter.Boyle@portbris.com.au

Loke, K.H.

Polyfelt Asia, Kuala Lumpur, Malaysia. lokekh@polyfelt.com.my

Hornsey, W.

Soil Filters Australia Pty Ltd, Gold Coast, Australia. whornsey@soilfilters.com.au

Stevens, M.

Leighton Contractors Pty Ltd, Brisbane, Australia. Matt.Stevens@leicon.com.au

Keywords: Brisbane, geotechnical, geotextile, marine conditions, soft clay

ABSTRACT: Stage 1 of the Future Port Expansion (FPE) Project located at the Port of Brisbane, Fisherman Islands involved the design and construction of a 4.6 km long seawall. The Seawall up to 8 m high, was constructed in waters up to 6 m deep and extends 1.8 km into Moreton Bay from shore. The factors which significantly impacted its design and construction, included the weak and deep soft clay subsoil profile, potential issues related to settlement, instability and loss of materials due to seabed penetration, marine conditions, and environmental concerns due to the proximity of the sensitive Moreton Bay Marine Park. High strength geotextiles up to 850 kN/m were used to overcome stability issues related to weak marine clay at the seabed and a filtration geotextile was used to protect the sand pancake below the rock bund. Damage trials were conducted on the selected geotextiles to assess the potential for damage from rock placement and trafficking.

1 INTRODUCTION

The Port of Brisbane is located at the mouth of the Brisbane River at Fisherman Islands in Brisbane. The Port land has seen rapid development due to increased Port activities and this growth is expected to continue for the next 25 years and beyond. The Future Port Expansion (FPE) Project will provide the land to cater for the increased demand in the future.

The ultimate objective of the FPE Project is to allow the Port to reclaim and develop an additional 230 ha of port land including extending the current quayline by a further 1800 m. The reclamation will be carried out using channel maintenance dredging materials. The first stage of this process was the construction of a 4.6 km long and up to 8 m high seawall to encompass the area so that reclamation could be carried out in an environmentally friendly and controlled manner.

The client used an Alliance delivery mechanism to deliver Stage 1 of the project because of the significant geotechnical, environmental and construction risks and constraints associated with the project. These included, highly variable soft clays extending over 30 m below the seabed on the eastern wall alignment, the close proximity of the Moreton Bay Marine Park, varying water depths, wind and expected sea conditions during construction.

Preliminary designs indicated the consistency of the marine clay at seabed level to be generally too weak to support high embankments unless the ground was improved or the construction staged allowing the clay to gain some strength. Most options were not feasible due to uncertainties on the effectiveness of the method, time constraints and/or associated costs. The use of a high strength geotextile was ultimately assessed to be the most cost effective and least risk solution.

A rock embankment placed on a high strength geotextile laid on the seabed was the design adopted where the seabed is shallow (1 m below low water). However in the deeper areas (3.5 m below low water), a wide sand pancake was included in the design because of weaker subsoil conditions (see design section for East Bund in Figure 1). The rock bund forming the upper part of the seawall was then placed on this sand pancake. During construction an appropriate filtration geotextile was selected to cover and contain the sand to prevent losses from the effects of tides and waves. Damage trials were conducted on the selected geotextiles to assess whether significant damage would occur during the placement of the rock and construction trafficking above and what allowance should be made for these effects.

2 SITE CONDITIONS

Based on the published geology map of Brisbane (1:100,000 scale), the site is underlain by Quaternary marine deposits consisting of “fluvial lithofeldspathic sublabilite sand and muddy sand”.

The main geological formations across the project site can be summarized as Holocene deposits overlying Pleistocene deposits, which in turn overlie the Petrie Formation, which consists of basalt bedrock. The Holocene alluvial deposit consists of two sub-layers with the upper layer generally between 0 to 4 m thick, comprising mainly sands with interlayered soft clays and silts. The lower layer comprises very soft to firm compressible clay generally normally consolidated from about 3 m depth below the seabed.

Along the East Bund, the soft clay at shallow depth is weak, having undrained shear strength values of 3 to 5 kPa, increasing towards the shoreline. The thickness of the layer varies from about 8 m to 30 m along the alignment.

3 GEOTEXTILE DAMAGE TRIALS

At the initial stages of the design, risk assessments were carried out. Damage to high strength geotextiles during rock placement and trafficking was identified as a significant hazard. However, it was recognized that downrating the basal geotextile strength, was an acceptable way to treat such issues in the design. Theoretical formulae were available to assess the requirements of a geotextile but not to assess the damage factors. There were also no documented experiences on damage due to trafficking on rock placed on a geotextile. Also of great concern was the potential for damage of the filtration fabric, because of the potential consequences if sand was sucked out by the tides leading to collapse of the rockwall above and consequent major failures.

From the outset it was decided to carry out a set of field trials to assess these effects using typical rockcore and armour materials to be used on the project.

3.1 Basal High Strength Geotextile

Although trials were conducted on several products only the trials conducted on the materials of the successful tenderer are discussed in this paper. The geotextiles tested were Maccaferri Rock WX200 (200 kN/m) & WX800 (800 kN/m) manufactured by Polyfelt Asia and supplied via Maccaferri Brisbane.

The trials were conducted in one of the reclamation paddocks filled with dredged mud capped off with a 2 m thick sand base. Dynamic

Cone Penetrometer testing conducted to assess the strength variation of the base generally indicated medium dense conditions.

The geotextile was supplied 4 m wide, which was stitched together to form a panel of about 12 m x 12 m. Two types of seams (J – Seam and a Butterfly Seam) were used to make an additional check on the effects on seams.

To hold the geotextile in place immediately after placement, smaller rock was placed as a weight along the edges of the test panel. Another issue of concern was the effect of larger rock falling on ballast rock placed to keep the geofabric in place on the seafloor. To simulate this and assess possible damage, a row of smaller rock was placed along the centreline parallel to the warp direction.

The panel was divided into 4 equal cells so that the seams were running along the centerlines of the cells. The trials were conducted using maximum 300 mm rock core with varying the number of drops and/or drop height. The two drop heights employed were 1.5 m and 3.0 m. The latter was used only as an assessment of the worst case scenario as generally the drop height employed during actual construction was always less than 1.5 m. Even the 1.5 m drop is somewhat conservative because in the Project part of the drop would be cushioned by water buoyancy.

On completion, rock core was carefully removed from the geofabric by hand after the bulk was removed by excavator bucket to assess, measure and photograph the damage prior to quantifying the damage. To assess the effect of construction vehicle movement, the removed rockcore was placed over the geofabric to form an access track wide enough for a 45 T excavator to travel. The length of the access track was about 5 m and the height was 1.0 m. This track was then subjected to 16 passes of the excavator moving parallel to the weft direction. The number of passes used was excessive compared to actual conditions during construction.

For the basal geotextile, the damage was calculated as a ratio of the width of damaged section over the total width of the panel or cell. Random parallel lines were drawn and the assessment for each line was assessed and only the worst case is summarized in Table 1.

The results indicated that:

- Except for an outlier, the damage factor varied between 1.2 and 1.8.
- WX800 showed better resistance than WX200.
- Tracking damage is more significant than damage created by rockcore drops.
- WX200 was significantly damaged by the tracking trial.

Table 1 – Summary of damage factors (Basal Geotextile)

| Test Locn. | Drop | Factor Worst Case | Remarks |
|------------|----------|--------------------------------|-------------------|
| M200/1 | 2 x 1500 | 1.7 | J Seam |
| M200/2 | 1500 | 2.4 | J Seam |
| M200/3 | 1500 | 1.4 | Test over ballast |
| M200/4 | 1500 | 1.6 | B Seam |
| M200/5 | 3000 | 1.8 | B Seam |
| M200 | Tracking | 60-70% of test section damaged | |
| M800/1 | 1500 | 1.3 | |
| M800/2 | 1500 | 1.2 | Test over ballast |
| M800/3 | 1500 | 1.2 | B Seam |
| M800/4 | 1500 | 1.4 | B Seam |
| M800/5 | 3000 | 1.5 | J Seam |
| M800 | Tracking | 1.8 | |

Based on the test results it was decided as a minimum to use geotextiles whose strength is at least double the 200 kN/m strength. A constant damage factor of 1.7 was used for all grades of geotextile between 400 kN/m and 850 kN/m used on the project.

3.2 Filtration Geotextile

The client was very concerned about the effects of rock placement and trafficking on the filtration geotextile covering the cohesionless white sand. Therefore the damage trials carried out on the filtration geotextile were more extensive. The geotextile trialed was a 1200 g/m² nonwoven staple fibre material (Terrafix 1200R) supplied by Soil Filters Australia.

As the filtration geotextile is placed over a sand pancake at and below the low tide level and the rock was to be placed and not dropped, only trafficking trials were conducted. The geotextile was anchored to an area of moist, loose to medium dense white sand in a reclamation paddock and 0.3 t armour rock placed (by excavator) over the geotextile to varying heights. The rock surface was divided into 4 sections, each approximately 4 m square, so that several trials could be conducted.

The results of a series of trials conducted with a 30 T excavator are summarized in Table 2.

Table 2 – Summary of damage factors of trials T1 to T7

| No. | Material cover and no. of passes | No. of fabric punctures |
|-----|---|--|
| T1 | 0.3 m of fine sand – 6 passes | Nil |
| T2 | no cover - 6 plus 1 slight screw of tracks | Nil |
| T3 | 1.0 m of fine core – 12 passes | 1 *100 mm tear [#] |
| T4 | 0.35 m of 60/40 mm crushed aggregate – 6 passes | Nil |
| T5 | 1.2 m of 0.35 t armour rock over 0.3 m of fine sand – 12 passes | Nil |
| T6 | 0.9/1.0 m of 0.35 t armour rock – 12 passes | 1*75 mm tear [#] and 6 tears (20-30 mm) |
| T7 | 0.3 m crushed concrete 75 mm - passes | Nil |

(# Damage assessed to be by bucket on uncovering test panel)

There were numerous indentations which were also recorded but not included in the above table. The presence of indentations indicated the significantly high strain the geotextile could withstand without rupture.

Further trials T8 to T10 were conducted with a 45 T excavator using previously tracked panels (T8 & T10) and a new panel (T9). The results summarized in Table 3 indicate that the damage from the 45 T excavator was greater than that from the 30 T. Also the damage on re-used geotextile was greater.

Table 3 – Summary of damage factors of trials T8 to T10

| Trial No. | Material description | No. of passes | No. of fabric punctures (tear width) |
|-----------|----------------------|------------------------|--------------------------------------|
| T8 | 1.1 m of armour rock | 12 plus 3 track screws | 3 (50-75 mm) |
| T9 | 1.0 m of core rock | 12 plus 3 track screws | 6 (10-50 mm) |
| T10 | 1.1 m of armour rock | 12 plus 3 track screws | 12 (10-150 mm) |

For trials T11 to T13, 1.0 m of core rock (T11) and 1.0m of armour rock (T12 & T13) were placed over new fabric and subjected to 12 passes of a 30 T excavator plus 4 track screws on T11 and 6 on T12 and T13. No punctures were observed in T11 and only two tears, maximum 25 and 75 mm, were observed on each T12 and T13 panels respectively.

Subsequent to Trial T11, approximately 0.3 m thick layer of core rock was placed on the previously trafficked geotextile and was subjected to the following at the same location:

- Full downward pressure of excavator bucket
- Four free thumps of the bucket
- Bucket screwing causing all rock to move.

The above actions produced only two (2) small (30 mm) punctures indicating the robust nature of the geotextile used.

4 GEOTEXTILE PLACEMENT FROM THE BARGE

On the Project, a ‘multipurpose’ barge was used for laying both geotextiles and for placing the sand through a spreader system. A flat-top barge, 53 m x 17 m, was modified for the Project (see Figure 2). The unloaded barge has a draft of 0.6 m.

In general the barge consisted of 3 zones:

- The high strength geotextile deployment zone on the port side of the barge.
- The ballast storage and loading zone on the starboard side of the barge, later used for the deployment of the filtration geotextiles.

- The barge controls, facilities, power and hydraulic systems running along the centre of the barge.

A tug was used to move the barge from the load out facility to site where it assisted in setting anchors. The barge positioned and moved itself once set with the hydraulic winches. At the completion of an anchor set, the tug would assist in retrieving the anchors and returning the barge to the load out facility.

Geotextiles were stitched offsite using a J seam into panels up to 42 m wide and 100 m long. The basal geotextile was rolled over in front of the barge and under as shown in Figure 2 with the initial panel done by divers. To avoid geotextile folding transversely 12 mm reinforcement bars were attached to the geotextile with cable ties at 10 m spacing to hold the geotextile tight. Ballast was placed to hold the geotextile in place on the seabed.

The filtration geotextile was required to cover the sand and separate the sand from rock above to minimize sand losses due to wave action. The filtration geotextiles were stitched together using a pray seam stitch to panels of size 32 m x 40 m and transported to the site. The filtration geotextile panels were placed on top of the sand straight off the starboard side of the barge (the area previously used as ballast storage during the placement of the high strength geotextile) as the sand was placed from the sand spreader (attached to the starboard side of the barge). To minimize the risk of the geotextile moving, rock was placed to cover the fabric at the crest (using land-based methods) as soon as practical.

5 CONCLUDING REMARKS

Geotextile damage trials were conducted to assess the damage due to rock placement and due to construction trafficking. The damage factors calculated were successfully used in the design of the high strength geotextiles. The trials conducted to assess the damage on filtration geotextiles due to construction trafficking indicated that the damage was minimal if 1200 R geotextile was used and the

excavator weight was limited to 30 T as long as a 800 mm minimum height of rock cover is used before construction traffic is allowed to traffick it.

The FPE Seawall Project Stage 1 was designed based on the results of the trials conducted and the construction was successfully completed in March 2005 (Figure 2).

ACKNOWLEDGEMENTS

The assistance given by Alliance participants including Port of Brisbane Corporation (Client), Leighton Contractors (Contractor), WBM Oceanics (Hydraulics Consultant), Coffey Geosciences (Geotechnical Consultant) and Parsons Brinckerhoff Australia (Civil Consultant) is gratefully acknowledged.

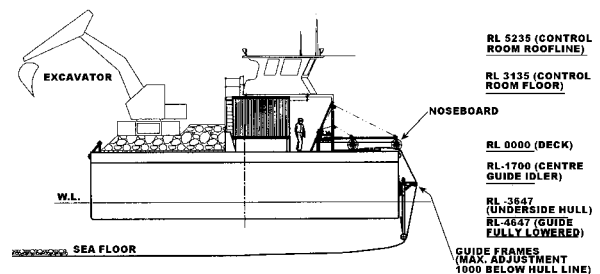


Figure 2 Placement of High Strength Basal Geotextile



Figure 3. Completed Seawall

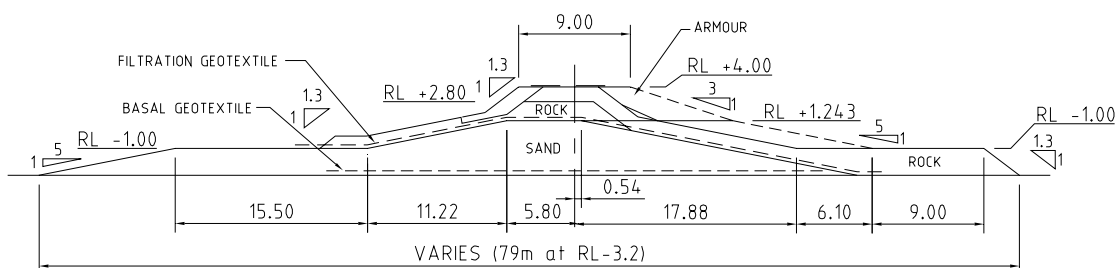


Figure 1. Typical Section on East Bund

APPENDIX 12:

- **GEOTEXTILE INFORMATION**
LETTER FROM GEOFABRICS
AUSTRALIA



A.B.N. 23 005 479 961

11 Production Avenue, Molendinar
Gold Coast, QLD, 4214, Australia
Telephone: (07) 5594 8600
Facsimile: (07) 5563 3727

TLB Engineers
514 Miller Street
Cammeray
NSW
2062

Attn: Mr. Howard Bersten

RE: INNER WEST MARINA GEOTEXTILE DURABILITY

Dear Howard

I would like to confirm that ELCOMAX R range of polyester staple fibre geotextiles will have a design life of greater than 100 years when submerged in saline water below a rock cover. Polyester is resistant to biological and hydrocarbon attack.

Should you require any further information please do not hesitate to contact me on 0438 069 581.

Yours Faithfully

Warren Hornsey
National Technical Manager
Geofabrics Australasia Pty Ltd



Quality
ISO 9001

www.geofabrics.com.au

Australian manufacturers of bidim® geotextiles & Megaflo® drainage products

APPENDIX 12:

▪ GEOTEXTILE INFORMATION

**ARTICLE ENTITLED: “CHEMICAL
AGING EFFECTS ON THE PHYSIO-
MECHANICAL PROPERTIES OF
POLYESTER AND POLYPROPYLENE
GEOTEXTILES”**

Chemical Aging Effects on the Physio-Mechanical Properties of Polyester and Polypropylene Geotextiles

A. Mathur^a, A. N. Netravali^{a*} & T. D. O'Rourke^b

^aFiber Science Program, Department of Textiles and Apparel, ^bCivil and Environmental Engineering, Cornell University, Ithaca, New York 14853-4401, USA

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ABSTRACT

The influence of groundwater chemistry on the durability of geotextiles is important for the design of municipal and hazardous waste landfills, geotextile reinforcement of slopes and subgrades, and earth retention systems. A series of tests are described in this paper, which explore the effects of various pH and saline environments on geotextiles, thus contributing to an improved understanding of durability as a basis for design. Accelerated aging was performed on polyester and polypropylene geotextiles at room temperature and temperatures elevated to 95°C for six months in saline (pH ~8), strong alkaline (pH 10) and acidic (pH 3) media. Property changes as a result of aging were studied using tensile testing, differential scanning calorimetry (DSC), thermogravimetric analysis (TGA) and intrinsic-viscosity (I.V.) measurements. Scanning electron microscopy (SEM) was employed to study changes in the surface topography of the fibers upon aging. An Arrhenius model was used to extrapolate results of this short term study to the actual lifetime of the geotextiles.

Results indicate that polyester undergoes hydrolytic degradation under both acidic and alkaline conditions at and above the glass transition temperature, with the degradation being more severe under alkaline conditions. The polypropylene geotextile, on the other hand, was relatively inert to the pH conditions and showed no changes in strength. An increase in crystallinity in the initial period of aging was observed for both polyester

*To whom correspondence should be addressed.

and polypropylene. In polyester, this was due to preferential attack on the amorphous regions whereas in polypropylene this may be due to nucleation growth and lamellar thickening.

1 INTRODUCTION

Geotextiles have played an increasingly important role in the past decade in promoting secure landfills, stabilizing roadbeds and embankment foundations, and reinforcing slopes and earth retention systems (Ingold *et al.*, 1988; Giroud, 1984; Koerner, 1986; IFAI, 1990). In landfills, for example, geotextiles are used to filter and separate drainage layers from adjacent waste and soil, thus contributing to the unimpeded collection of leachates and restricting the build-up of internal fluid pressure. Depending on the facility into which they are incorporated, geotextiles may need to perform for relatively few years (as in the case of temporary retaining structures) or for 100 years or more (as in the case of landfills).

To survive aggressive underground environments, geotextiles must be resistant to various forms of attack, such as mechanical, chemical and biological. Chemical attack may be initiated directly by acidic or alkaline soils or indirectly by the active wastes present in the landfills. Depending on the type of chemical compound, changes in the polymer structure can be brought about by oxidation, chain scission, crosslinking, swelling or dissolution of the polymers, volatilization or extraction of ingredients of the polymeric compound, or an increase in the crystallinity of the polymer. In addition, the effects of chemical degradation may be accelerated by the service temperature.

A great deal of information has been compiled on the chemical resistance of polymers from a number of geotextile manufacturers (Horz, 1986). Cassidy *et al.* (1992) have summarized the resistances of various geosynthetic materials to different exposure media and the mechanical and chemical test methods which could be used to evaluate the ensuing property changes. More specifically, the effects of high levels of alkalinity on the flow and strength behavior for several geotextiles have been investigated by some researchers (Halse *et al.*, 1987; Montalvo, 1989). Accelerated aging in a chemical environment has also been studied to predict the long term properties of PET (polyester) and PP (polypropylene) geotextiles (Cassidy *et al.*, 1990). Koerner *et al.*, (1992) have suggested the use of the Arrhenius model to predict the lifetime of geosynthetics by studying the changes in the physical and mechanical properties after accelerated aging tests. In general, polypropylene fibers and geotextiles are relatively inert to chemical attack, whereas polyester geotextiles show limited resis-

tance to strong acids and alkalis. Results obtained for polyester geotextiles aged for 120 days at 22°C and 50°C in de-ionized water, sodium hydroxide (pH 12) and calcium hydroxide (pH 12.4) in the laboratory indicate the strong susceptibility of polyester to alkaline hydrolysis at elevated temperatures (Sprague, 1990).

Differences in physical and chemical properties of various geotextiles depend closely on the constituent fiber-forming polymers. The chemical and the supermolecular structure of the fiber as well as the method of manufacture of both the fiber and geotextile have a strong bearing on the geotextile properties.

Polypropylene (PP) generally assumes a linear structure, but due to the methyl group (CH_3), it can exist in three forms of different tacticity (i.e. the CH_3 group may be present in three different spatial arrangements: isotactic, atactic and syndiotactic). Most commercial polymers and fibers of PP are approximately 90 per cent isotactic and crystallize in a helix form (Cooke & Rebenfeld, 1988). The methyl (CH_3) side group on the repeat unit of PP creates some reactive sites along the polymer backbone by the formation of a tertiary carbon which makes it susceptible to chemical attack.

Polyester (PET) is synthesized from terephthalic acid and ethylene glycol. The phenyl ring structure and the adjacent ester linkage supply rigidity and molecular flexibility, respectively, to the polymer through resonance stabilization. However, under strong acidic and alkaline conditions, PET undergoes hydrolysis, wherein a long chain linear molecule is split by a water molecule resulting in a scission of an ester linkage (Risseuw & Schmidt, 1990). In addition, hydrolysis in alkaline media has been found to be more severe as compared to hydrolysis in an acidic environment (Risseuw & Schmidt, 1990; Reich & Stivala, 1971).

The chemical properties of fibers, such as solubility and chemical resistance, are largely dependent on their chemical structure. These properties can be further influenced by the supermolecular structure of the fibers. Fibers are generally modeled as semi-crystalline, oriented polymers that take on a two-phase structure. This two-phase structure consists of crystalline regions, where the polymer chains are well oriented and closely packed into a three-dimensional ordered lattice structure, and non-crystalline (amorphous) regions, where the polymer chains are present in a random coil configuration with little or no packing regularity. Many of the important properties such as chemical absorption, extensibility and resilience of fibers are directly associated with these amorphous regions (Cooke & Rebenfeld, 1988).

The observation and examination, at a macrostructural as well as at a microstructural level, of geotextiles installed for several years under highly

diverse conditions, can reveal important information about their physical and mechanical properties. While long-term *in situ* tests are indispensable, they have the disadvantages of long durations, poor reproducibility and high cost. Under such circumstances, it is important to simulate the aging processes in a shorter time. While, in practical applications, changes occur slowly and are due to relatively weak influences, accelerated tests are based on more intensive action over a short period.

In this study, accelerated chemical aging was carried out at different temperatures and time periods under controlled conditions. The effects of aging on the physical and mechanical properties were determined using several analytical techniques such as tensile testing, thermal analysis by differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA), intrinsic viscosity (I.V.) and scanning electron microscopy (SEM). Using these techniques, changes occurring at the microstructure level were analyzed. Finally, an attempt has been made to fit the data to a standard Arrhenius aging model to predict the long term performance of the geotextiles.

2 EXPERIMENTAL PROCEDURES

Two geotextiles were selected for this study, namely: (i) PET/GT, a continuous filament, nonwoven, lightly needle-punched polyester geotextile; and (ii) PP/GT, a continuous filament, nonwoven, heavily needle-punched polypropylene geotextile. The continuous filament geotextiles were produced by the spun bonded process wherein the fibers were continually extruded, drawn, cooled, sprayed to form a uniform web and needle-punched in one continuous operation. Typical values of some geotextile properties supplied by the manufacturers, are presented in Table 1.

2.1 Exposure conditions

Standard buffer solutions of pH 3 and pH 10 were used for the acidic and alkaline environments, respectively. The saline environment was simulated using a synthetic sea salt (Instant Ocean) which is commonly used for salt water fish aquariums (Mandaikar, 1985). Sea water normally contains a number of cations (weak acids), and although there are a lesser number of anions (bases or alkalies), some of these, such as chlorine, are quite strong. As a result, sea water is slightly alkaline, with pH ranging from 7.5 to 8.3. Since this was not a standard buffer, the solution was replaced every ten days in this study.

Specimens of dimensions suitable for tensile testing were randomly cut

Table 1
Physical Properties of the Geotextiles

| Property | PET/GT | PP/GT |
|-------------------|--|--|
| Mass/area | 252 g/m ² (7.4 oz/yd ²) | 218 g/m ² (6.4 oz/yd ²) |
| Thickness | 2.54–2.80 mm | 1.9–2.0 mm |
| Grab strength | 1.08 kN | 0.54 kN |
| Grab elongation | 80% | 50% |
| Average pore size | 0.21 mm | 0.21–0.15 mm |

from the rolls supplied by the manufacturers and aged at 21°C (room temperature), 45°C, 70°C and 95°C for a period of 2 weeks, 6 weeks, 12 weeks and 24 weeks (6 months) in 32 oz (811.2 g) wide mouth glass bottles. Three air circulation ovens were used for this purpose. The temperatures were maintained within $\pm 2^\circ\text{C}$ of the required temperature. Although temperatures as high as 70°C and 95°C may not be commonly observed in practice, they were used for two reasons. Firstly, at elevated temperatures, the reaction rates are higher. Secondly, these temperatures enabled us to study the degradation kinetics of polyester both below and above its glass transition temperature (T_g), of about 70°C. At the end of each exposure, the specimens were removed from the ovens, washed thoroughly in reverse osmosis water and dried for at least 24 h prior to testing.

2.2 Tensile testing

The tensile tests were performed on the Instron Universal Testing Machine (Model #1122) interfaced with a Hewlett Packard 86B computer. To observe the effects of the accelerated aging treatment, the Cut Strip test was used in accordance with ASTM D 1682, which gave easily reproducible results. A gauge length of 76 mm (3 in) was used for a strip width of 25.4 mm (1 in). A crosshead speed of 200 mm/min was used which gave a strain rate of 2.63 min^{-1} . All specimens were conditioned at 21°C and 65% RH for at least 24 h before testing. Peak tensile strength (N/m) and elongation at peak strength (peak strain) in both machine and cross directions (since material is anisotropic) were obtained from the load vs elongation plots from an average of 10 readings.

2.3 Fiber tests

The deterioration of the fibers comprising the geotextile due to chemical aging has a strong bearing on the strength of the geotextile. The strength

of the geotextile is attributed to the network of fibers comprising the geotextile, with each fiber having its own contribution to the overall strength. The fiber strength, in turn, is directly related to the fiber morphology, the molecular weight and chemistry of the inherent polymer. Therefore, the tensile properties of the fibers before and after aging were also determined. To account for the variability in fiber diameters, fiber strengths are generally reported in terms of stress, for which the peak strength and area of cross section of the fiber were measured.

About 25–30 fibers each were carefully extracted from the polyester geotextiles for the untreated as well as for the extreme conditions. The peak fiber strength was measured on the Instron in accordance with ASTM D 3379. A gauge length of 20 mm and a crosshead speed of 20 mm/min (a strain rate of 1 min^{-1}) was used for the test. Exact details of the procedure are discussed elsewhere (Netravali *et al.*, 1989). Fibers from the polypropylene geotextile, however, could not be tested for tensile strength, since the lengths of the extracted fibers were too short to be tested.

2.4 Thermal analysis

The temperature dependence of the property changes occurring in the polymer due to aging was evaluated by DSC and TGA. A Perkin–Elmer DSC-4 with a System 4 microprocessor controller and a Model 3700 data station were used in this study. Specimens weighing 5–8 mg were scanned from 50°C to 300°C at a rate of 10°C/min in a nitrogen atmosphere and their melting characteristics (the melting point and the enthalpy of fusion) recorded. It was difficult to detect the glass transition temperature (T_g) for the polyester specimens in the first run due to the plasticization effect of the diffused water. The specimens were therefore quenched at 60°C/min and reheated at 10°C/min to eliminate the volatiles and other plasticizers, mainly water. The T_g , the onset of melting (T_m) and heat (enthalpy) of fusion (ΔH) were determined for the specimens treated under extreme conditions and compared to the values obtained for the untreated specimens.

Thermogravimetric studies were performed using a Perkin–Elmer TGS-2 with a System 4 microprocessor controller and a Model 3700 data station. Typically, a small piece of the geotextile (2–5 mg) was placed in a platinum pan enclosed in the furnace, and heated at 40°C/min in a nitrogen atmosphere. The degradation onset temperatures (T_d) and the weight losses for specimens exposed to extreme conditions were determined and compared with those for the untreated specimens.

2.5 Intrinsic viscosity

The degradation of polymers due to chain scission is reflected in changes in the molecular weight and molecular weight distribution. The molecular weight of a polymer is directly related to its intrinsic viscosity, $[\eta]$, by the following relationship:

$$[\eta] = KM^\alpha \quad (1)$$

where M is the molecular weight of the polymer, and K and α are material constants.

Since polyester is susceptible to chain scission resulting from hydrolysis, the $[\eta]$ values for polyester geotextiles were expected to decrease after aging. Representative specimens obtained under extreme treatment conditions were sent to Firestone Fibers and Textile Company for $[\eta]$ determination. Intrinsic viscosity was measured in 25/75, para-chlorophenol and tetrachloroethane mixture at 25°C using a standard viscometer.

2.6 Electron microscopy

Photomicrographs of fiber surfaces obtained using a Scanning Electron Microscope (Jeolco JSM 35) were inspected for evidence of pitting, etching or scratching of the individual geotextile filaments and for changes in the geotextile structure.

3 RESULTS AND DISCUSSION

A discussion of the test results for polyester geotextile (PET/GT) and polypropylene geotextile (PP/GT) are now given.

3.1 PET/GT (polyester)

3.1.1 Tensile test results

Changes in the tensile properties in the case of PET/GT were ascertained by observing the changes in their load elongation behavior before and after aging for both fabric as well as fiber specimens of the geotextile.

3.1.1.1 Geotextile strength. PET/GT is a lightly needled nonwoven geotextile. Due to the loose assemblage of fibers, the application of stress initially aligns the fibers along the direction of stress prior to failure. This behavior is evident in the stress-strain plot shown in Fig. 1, where three

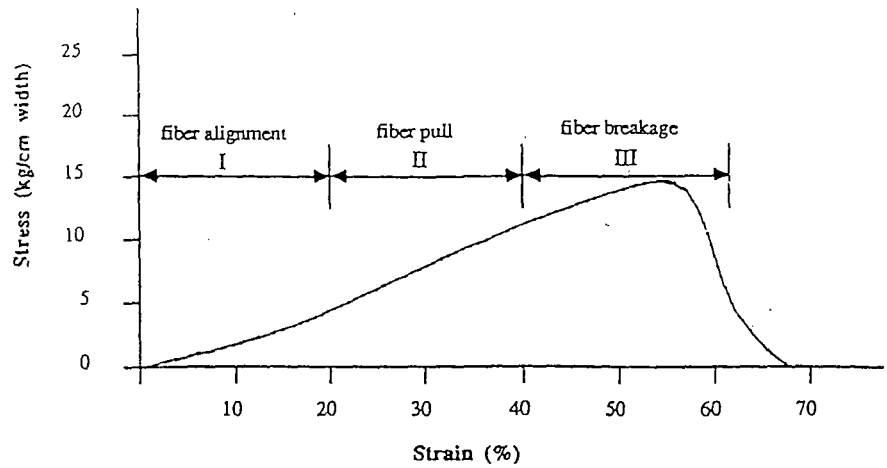


Fig. 1. Typical stress-strain plot for PET/GT.

distinct regions can be identified. The first region has a low modulus where the fibers align themselves in the direction of the stress. The second region exhibits a higher modulus. In this region, the fiber alignment is complete or further alignment becomes more difficult. This region also exhibits linear stress-strain behavior. Finally, in the third region, the modulus falls again as the fibers begin to break. While the fracture strength is influenced by the strength and orientation of the fibers in the geotextile, the fracture strain depends mostly upon the amorphous content in the fiber and the fiber orientation.

The average peak (breaking) stress for the untreated PET/GT geotextile was 15.37 kN/m with a corresponding peak strain of 65.36% in the machine direction and 12.65 kN/m with a peak strain of 64.60% in the cross direction. The higher strength in the machine direction reflects the anisotropy in the geotextile wherein a larger number of fibers are aligned in the machine direction than in the cross direction.

The plots of strength values obtained in the machine direction after each exposure condition are shown in Figs 2, 3 and 4. As shown in Fig. 2, no apparent change in the stress values is seen at either 21°C or 50°C in pH 10, even after 24 weeks of exposure. In contrast, a steady decrease in strength is observed as a function of aging at 70°C. At 95°C, an approximate 80% drop in strength occurs within the first 4 weeks of exposure, and the specimens dissolve completely within the next 2 weeks. A similar trend is observed for the specimens tested in the cross direction, which indicates that the effects of aging are not so much dependent on the structure of the geotextile as they are on the constituent fiber or the polymer type.

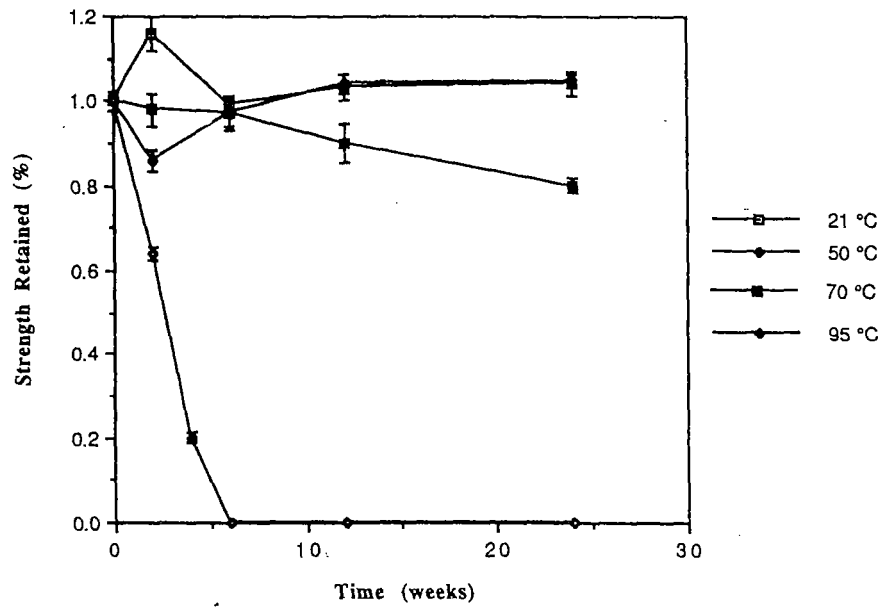


Fig. 2. Effect of pH 10 on PET/GT tensile strength.

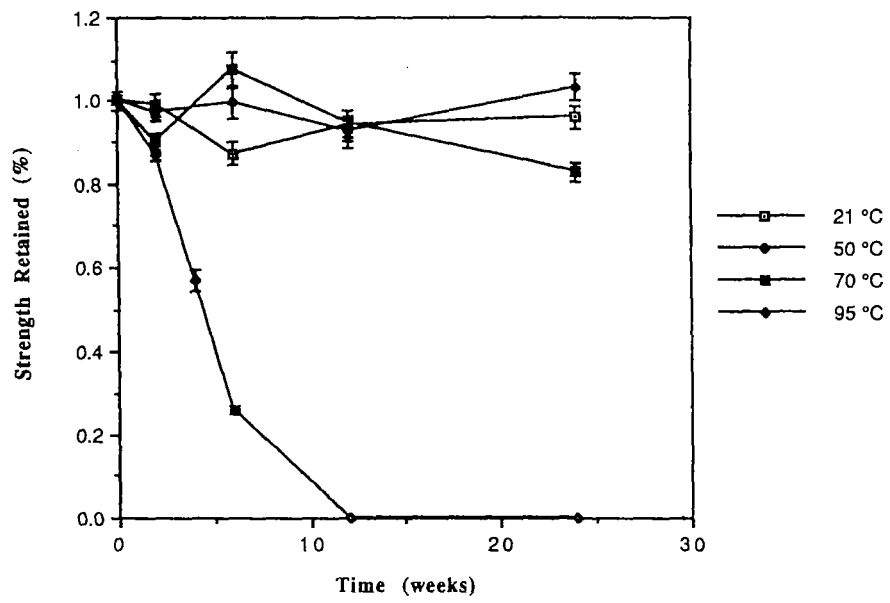


Fig. 3. Effect of pH 3 on PET/GT tensile strength.

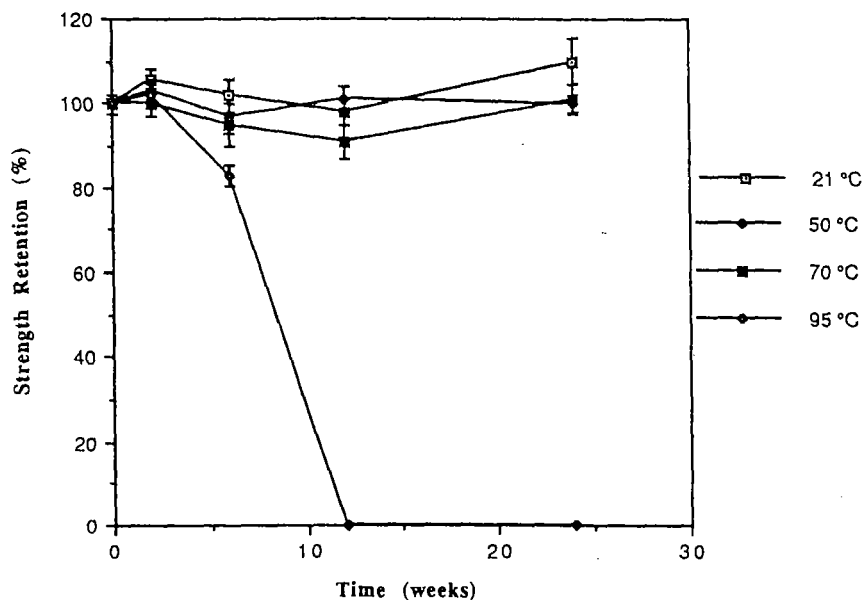


Fig. 4. Effect of sea water on PET/GT tensile strength.

The effect of pH 3 on the tensile strength of the PET/GT under various exposure conditions is shown in Fig. 3. As in the case with pH 10, for pH 3, there was no change in the strength values at 21°C and 50°C, while at 70°C, a slight strength reduction was observed after 24 weeks of aging. At 95°C, the effect of pH 3 was less severe than that obtained for pH 10, although the trend is similar. A 43% reduction in peak strength was observed after 4 weeks of aging and the specimens dissolved completely between the 6 week and 12 weeks aging period. Again, the results obtained in the cross direction followed a similar trend.

The action of sea water on PET/GT, as shown in Fig. 4, was milder than both pH 3 and pH 10. No significant change in strength was observed at 70°C, even after 24 weeks of exposure. At 95°C, however, a strength reduction of 18% was observed after 6 weeks of aging with complete dissolution occurring after 12 weeks.

Another noticeable observation was that the strains to failure for PET/GT decreased with increasing aging time for all pH conditions. Percentage retention of the failure strains after increasing periods of aging are shown in Figs 5, 6 and 7. For pH 10, the strain value for PET/GT decreased by around 15% after 24 weeks of exposure at 70°C and by 60% within 6 weeks at 95°C. Similar changes were obtained for pH 3, while for sea water conditions, the maximum reduction in strain was 15% after 6 weeks of aging at 95°C.

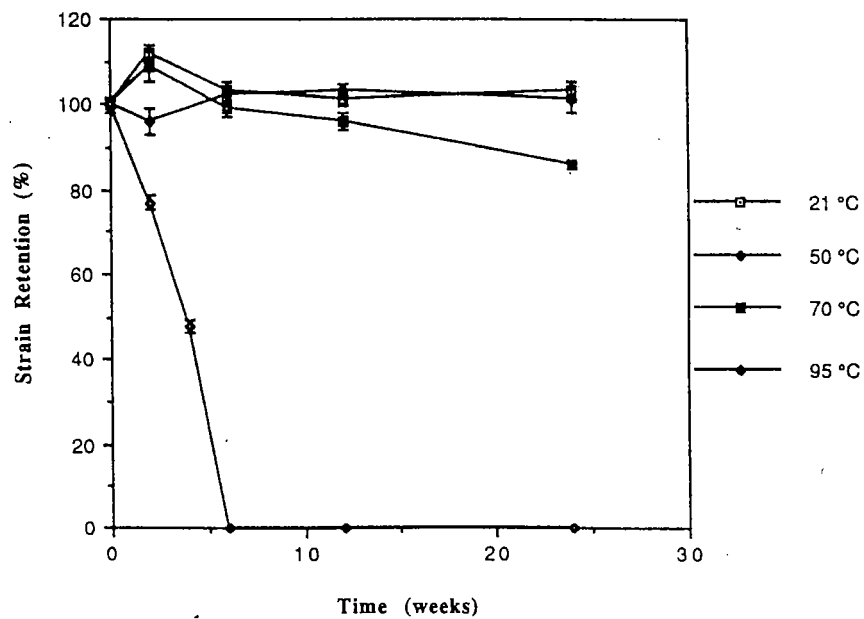


Fig. 5. Effect of pH 10 on PET/GT strain.

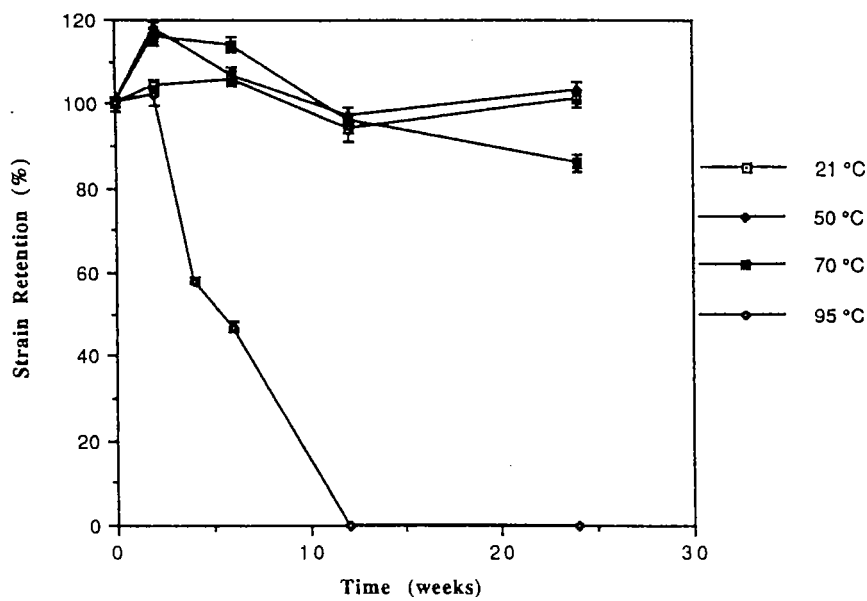


Fig. 6. Effect of pH 3 on PET/GT strain.

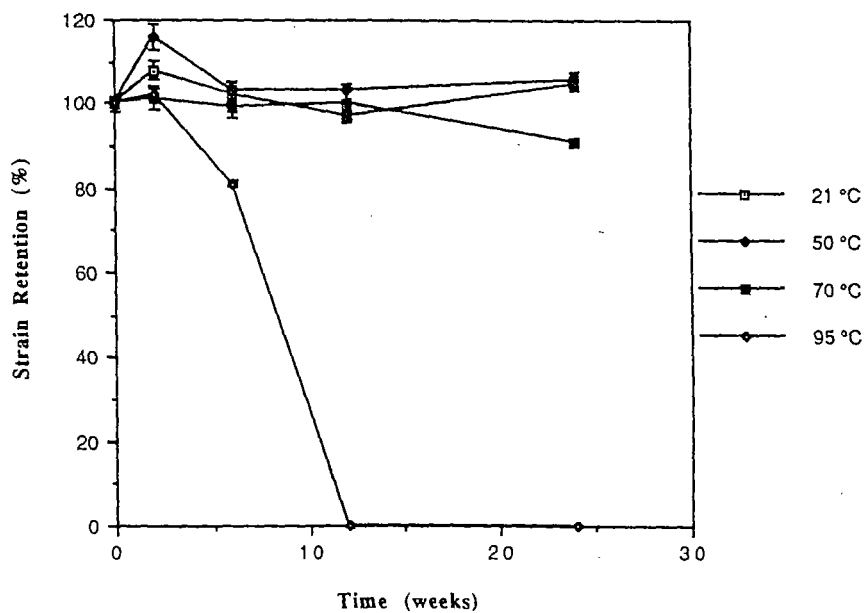


Fig. 7. Effect of sea water on PET/GT strain.

3.1.1.2 Fiber strength. Plots of the PET/GT fiber strength tests performed for the extreme conditions for aging temperatures of 70°C and 95°C are shown in Figs 8, 9 and 10. As evident from the results, the fiber strength loss shows a similar trend as that obtained for the geotextiles. The severity of fiber degradation is greater in alkaline media as compared to acid and sea water. The reduction in fiber strength after 4 weeks of aging at 95°C was around 63% for pH 10, 47% for pH 3 and 21% for sea water. The tensile results for both the geotextile and fiber indicate that PET/GT is relatively inert to chemical attack at temperatures below 70°C. However, at temperatures above the glass transition temperature of polyester (~73°C), such as 95°C in the present study, some severe hydrolytic degradation occurs. These results agree with those obtained by other researchers (Cassidy *et al.*, 1990; Sprague, 1990; Risseuw & Schmidt, 1990; Schneider & Groh, 1987). Hydrolysis in neutral water and acidic media is catalyzed by the free hydrogen (H^+) ions, while alkaline hydrolysis is due to the more reactive hydroxyl (OH^-) radicals (Risseuw & Schmidt, 1990).

3.1.2 Intrinsic viscosity measurements

The splitting or scission of the ester linkages due to hydrolysis, results in the reduction of the molecular weight. The molecular weight of a polymer

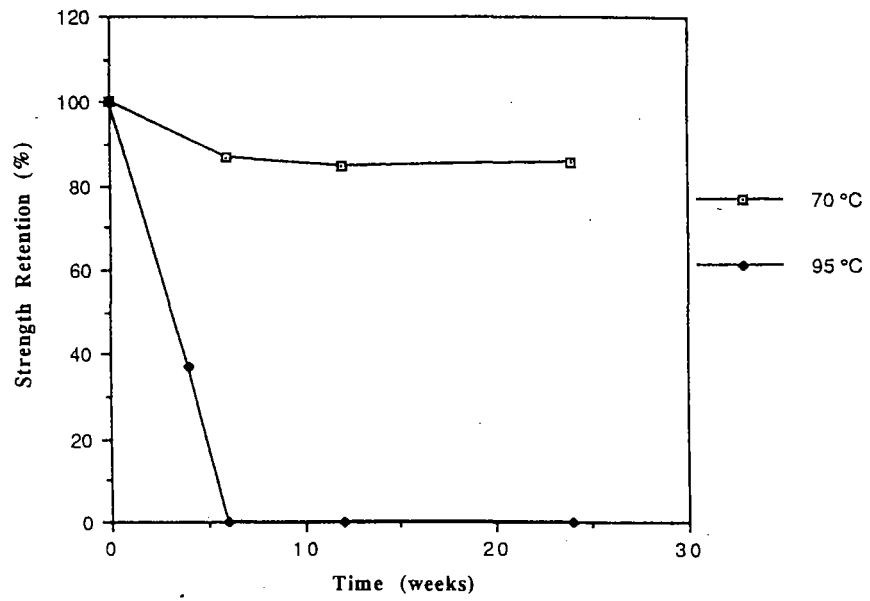


Fig. 8. Effect of pH 10 on PET/GT fiber strength.

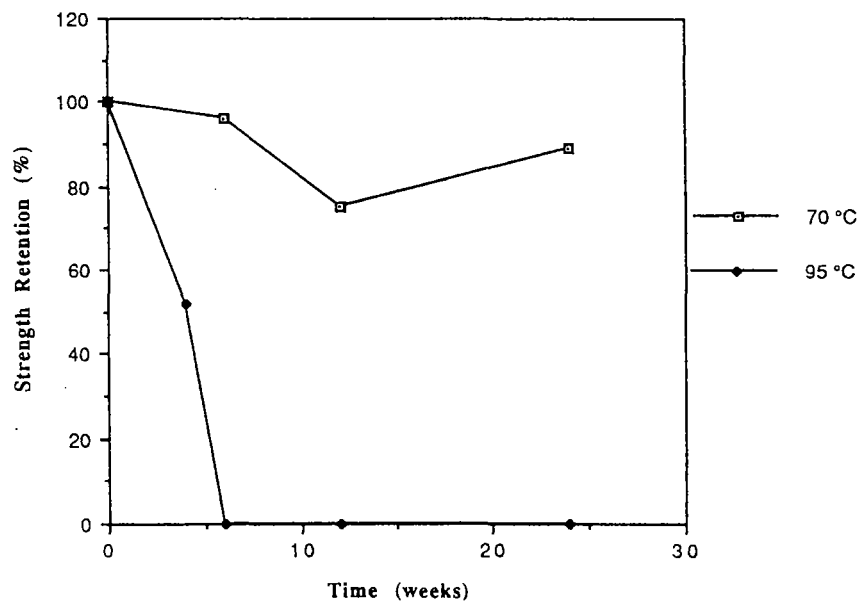


Fig. 9. Effect of pH 3 on PET/GT fiber strength.

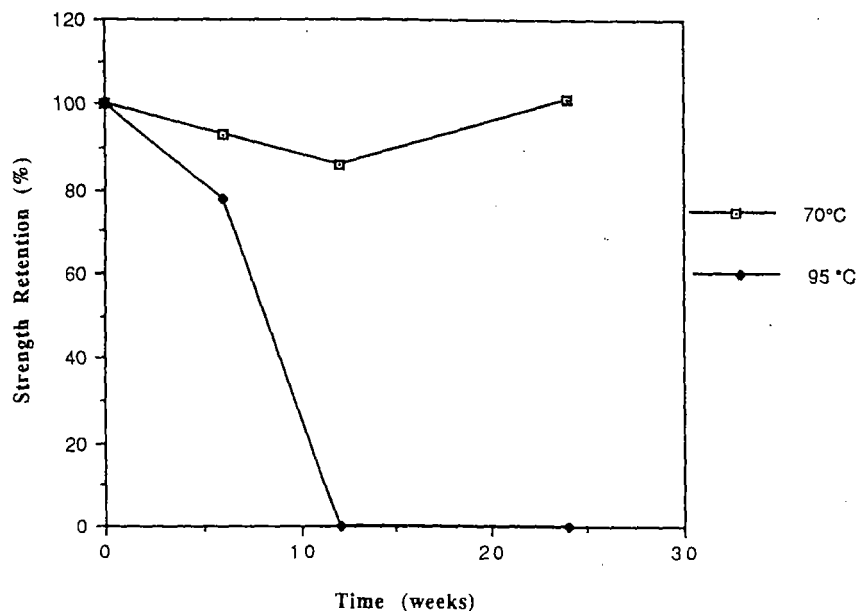


Fig. 10. Effect of sea water on PET/GT fiber strength.

is related to its intrinsic viscosity $[\eta]$ as explained earlier. Intrinsic viscosity data for PET/GT treated under some extreme conditions are presented in Table 2 below.

The $[\eta]$ results for 95°C indicate a significant reduction (greater than 50%) in the molecular weight of the polyester specimens confirming the molecular chain scission after hydrolysis. The $[\eta]$ results for 50°C, on the other hand show only a weak trend of reduced values with time implying that hydrolysis is at an incipient stage below the glass transition temperature.

Table 2
Intrinsic Viscosity (dl/g): PET/GT

| Temp | Untreated | 50°C | | 95°C | | |
|-----------|-----------|----------|----------|---------|---------|----------|
| | | 12 weeks | 24 weeks | 4 weeks | 6 weeks | 12 weeks |
| pH 3 | 0.612 | 0.596 | 0.602 | 0.233 | 0.220 | — |
| pH 10 | 0.612 | 0.598 | 0.605 | 0.288 | 0.253 | — |
| Sea water | 0.612 | 0.604 | 0.600 | — | 0.373 | 0.214 |

3.1.3 DSC results: PET/GT

Figure 11 shows a typical DSC thermogram obtained for untreated PET/GT, showing the melting point (T_m) between 250°C and 255°C with an enthalpy of fusion of around 50.21 kJ/kg.

Table 3 compares the onset of melting point (T_m) and the enthalpy of fusion (ΔH) for the untreated specimens and those treated under extreme conditions.

The T_m and ΔH data for all pH conditions at 70°C show a slight increase indicating an increase in crystallinity. However, the specimens treated in pH 10 at 95°C, where the hydrolytic degradation is more severe, behave differently. In contrast to degradation at 70°C, a decrease in both T_m and ΔH values was observed. While the melting point onset was lowered from 254.5°C to 248.6°C, the enthalpy of fusion decreased from 50.21 kJ/kg to 36.40 kJ/kg within six weeks of aging.

During the initial period at 70°C, the ΔH values seem to increase for the fibers treated with pH 10 and pH 3. We attribute this to the decrease in the amorphous content rather than the increase in the crystallinity. Degradation proceeds initially in the amorphous region which is considered 'open', with sufficient free volume or voids, compared to the crystal-

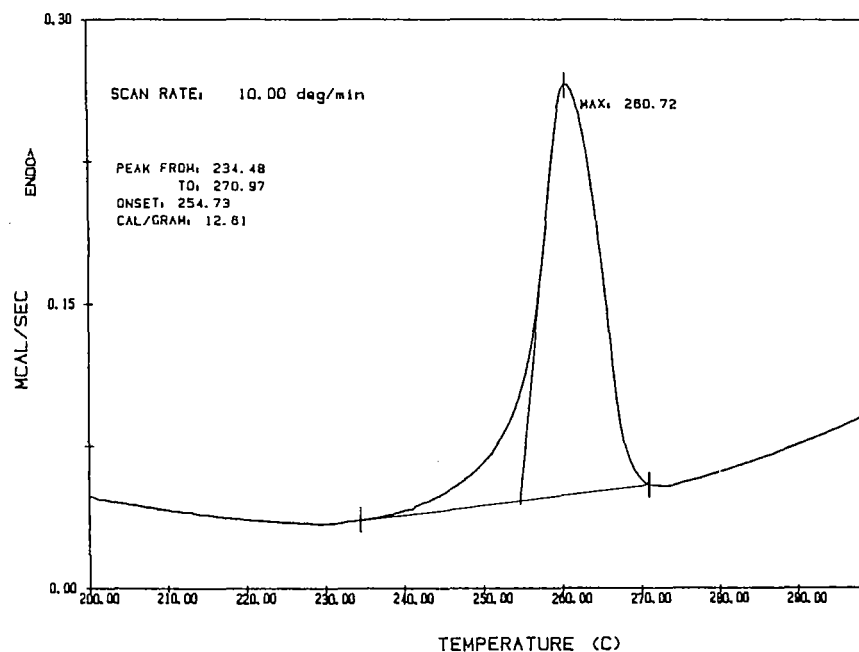


Fig. 11. Typical DSC thermogram for PET/GT.

Table 3
DSC Results for PET/GT

| Temp Time | Untreated | 70°C | | | 95°C | |
|-----------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| | | 6 wks | 12 wks | 24 wks | 2 wks | 6 wks |
| <i>pH 10*</i> | | | | | | |
| T_m (°C) | 253.4 (0.96) | 254.2 (0.45) | 255.0 (0.28) | 254.6 (0.70) | 254.5 (0.62) | 248.6 (1.19) |
| ΔH (kJ/kg) | 50.21 (2.05) | 58.16 (1.76) | 53.56 (1.38) | 54.81 (3.10) | 48.95 (3.26) | 36.40 (4.94) |
| <i>pH 3*</i> | | | | | | |
| T_m (°C) | 253.4 (0.96) | 254.2 (0.64) | 255.5 (0.84) | 253.2 (0.78) | 254.3 (0.47) | 252.3 (1.65) |
| ΔH (kJ/kg) | 50.21 (2.05) | 51.04 (3.68) | 55.22 (1.42) | 50.21 (2.18) | 47.70 (4.31) | 61.09 (3.47) |
| <i>Sea water*</i> | | | | | | |
| T_m (°C) | 253.4 (0.96) | 253.0 (0.69) | 255.2 (0.67) | 253.7 (1.1) | 255.0 (0.76) | 251.7 (1.74) |
| ΔH (kJ/kg) | 50.21 (2.05) | 50.63 (1.59) | 52.30 (3.56) | 49.79 (3.51) | 48.12 (2.43) | 49.79 (7.41) |

*Each reading is an average of three specimens with the standard deviations shown in parentheses.

line region, which is tightly packed and dense. This relatively high accessibility of the amorphous regions to water molecules causes the chains to hydrolyze into fragments during the initial period. As hydrolytic degradation progresses with time, the molecular fragments decrease in size until they are small enough to leach away into the surrounding medium, thus increasing the 'apparent' crystallinity. The molecular weight reduction due to the loss in material is reflected in the reduced strengths of the geotextile and fiber as well as the reduced intrinsic viscosity values for these conditions. This phenomenon occurs for the PET/GT geotextile treated in all the pH conditions during 12 weeks of aging at 70°C and continues for six months for specimens treated with pH 10.

An increase in crystallinity may also occur when undegraded chain segments remaining in the amorphous regions acquire more chain mobility, thus enabling them to get incorporated into the existing crystals (Jailloux & Verdu, 1990). This process, involving an increase in the density during aging, is called chemicrystallization (Ballara & Verdu, 1989; Jailloux & Verdu, 1990; Sprague, 1990). An increase in the melting temperature, T_m , and the enthalpy of fusion, ΔH , indicates possible lamella thickening linked to the chemicrystallization process.

With continuing chemicrystallization and leaching of the amorphous material, the crystallinity reaches a maximum, until a stage comes when the crystals start getting attacked. As a result, the crystal size decreases, which is manifested in a decrease in T_m , with an overall decrease in crystallinity in the polymer, as indicated by the lower ΔH values. Degradation of the crystalline regions, however, occurs much more slowly than the amorphous regions. This explains the drop in the melting point and enthalpy of fusion after prolonged exposure of six months at 70°C for pH 3 and sea water. In the pH 10 environment, where hydrolytic degradation is more severe due to the reactive hydroxyl groups, the crystals get attacked much earlier, i.e. within three months of aging.

At 95°C, the effects of aging differ slightly for the three pH conditions. In pH 10, this phenomenon is reflected both in the decrease in T_m and the large drop in the enthalpy of fusion from 48.95 kJ/kg to 36.40 kJ/kg within 6 weeks of aging. The increasing brittleness can also be attributed to the increase in the crystallinity of the polymer, since it is the amorphous regions which give the fiber its extensibility. For pH 3, where the hydrolytic degradation is not as severe as in pH 10, degradation seems to occur simultaneously in both amorphous and crystalline regions. While the 'apparent' crystallinity (ΔH) increases, the crystal size decreases which can be inferred from the lower T_m values. In sea water, the hydrolytic attack is the least severe and degradation in the two regions compete with each other. As a result, there is no significant change in the overall crystallinity of the fibers. However, the degradation of the crystalline region is reflected in the lower value of T_m after 6 weeks of aging at 95°C.

3.1.4 TGA results: PET/GT

Thermogravimetric analysis yields similar results for all the pH conditions. Figure 12 shows a typical thermogram obtained for the untreated PET/GT geotextile. The degradation onset for polyester was around 425°C and the weight loss around 86%. The 14% residual carbon, probably in the form of graphite, is contributed mainly by the decomposed benzene functional group (Hsuan, 1991). Table 4 compares the results obtained for PET/GT before and after aging for the adverse conditions. All the degradation onset temperatures (T_d) fall within the narrow range of 425–430°C, indicating no fundamental change in chemistry.

3.1.5 Microstructure: PET/GT

SEM photomicrographs of the untreated PET/GT and that treated for 6 weeks in pH 3 and pH 10 solutions at 95°C are shown in Figs 13, 14 and

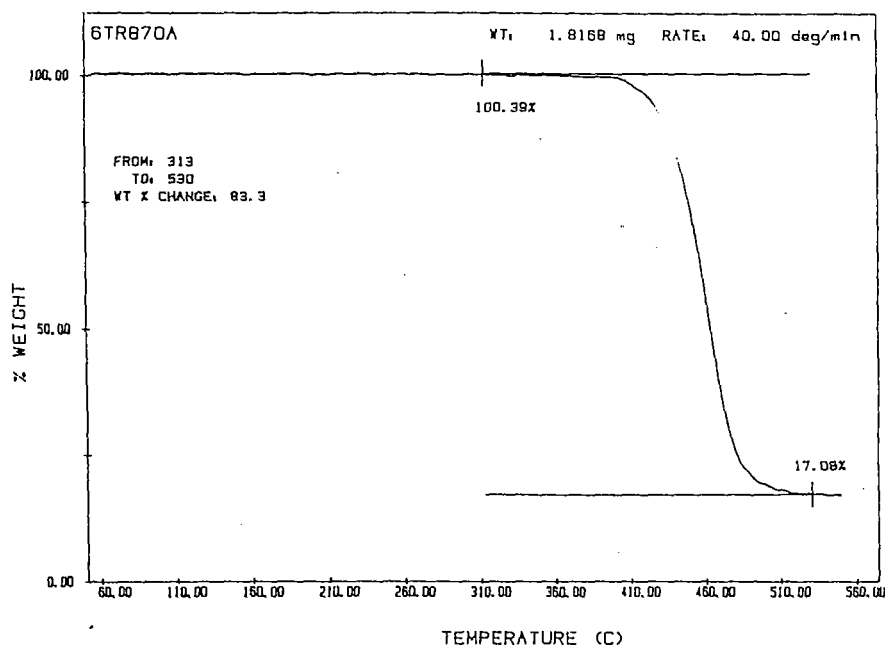


Fig. 12. Typical TGA plot for PET/GT.

15, respectively. They confirm the results of Halse *et al.*, (1987), Solbrig & Obendorf (1986), and Collins *et al.*, (1988) who showed that alkaline hydrolysis occurs primarily on the surface of the fiber. A loss of material is evidenced by etching marks on the surface of the fibers. Acid and sea

Table 4
TGA Results: PET/GT

| Temp | 70°C | | | | 95°C | | |
|-------------------|-----------|-------|-------|--------|--------|-------|-------|
| | Untreated | 2 wks | 6 wks | 12 wks | 24 wks | 2 wks | 6 wks |
| <i>pH 10*</i> | | | | | | | |
| T_d (°C) | 425.3 | 428.0 | 430.3 | 433.5 | 436.9 | 428.9 | 430.7 |
| Wt. Loss (%) | 87.2 | 85.3 | 85.4 | 84.4 | 82.2 | 86.5 | 83.2 |
| <i>pH 3*</i> | | | | | | | |
| T_d (°C) | 425.3 | 426.6 | 430.0 | 430.4 | 431.0 | 424.9 | 431.8 |
| Wt. Loss (%) | 87.2 | 86.1 | 86.4 | 88.0 | 87.3 | 85.7 | 86.1 |
| <i>Sea water*</i> | | | | | | | |
| T_d (°C) | 425.3 | 429.2 | 434.9 | 434.7 | 434.6 | 428.6 | 432.0 |
| Wt. Loss (%) | 87.2 | 84.5 | 83.9 | 85.5 | 82.9 | 86.5 | 84.8 |

*Each reading is an average of 3 specimens.

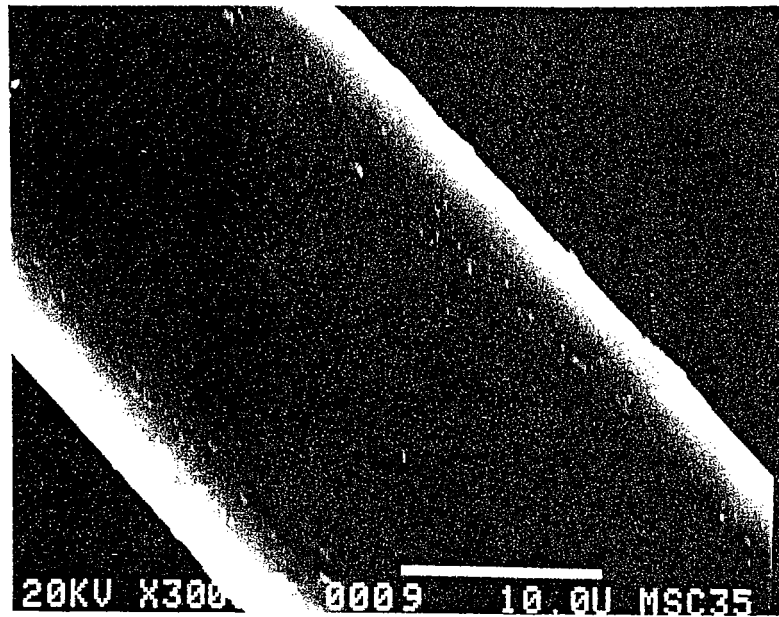


Fig. 13. SEM micrograph of untreated PET/GT.

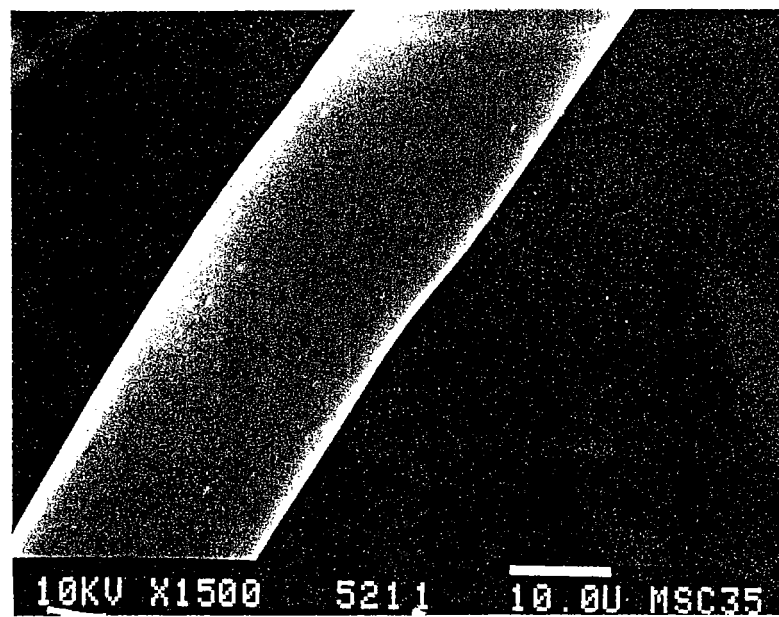


Fig. 14. SEM micrograph of PET/GT treated at pH 3 for 6 wks at 95°C.

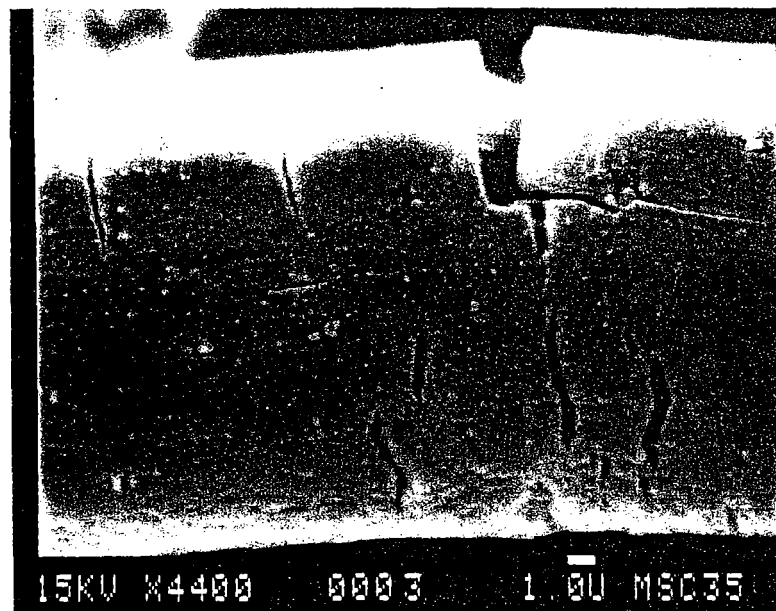
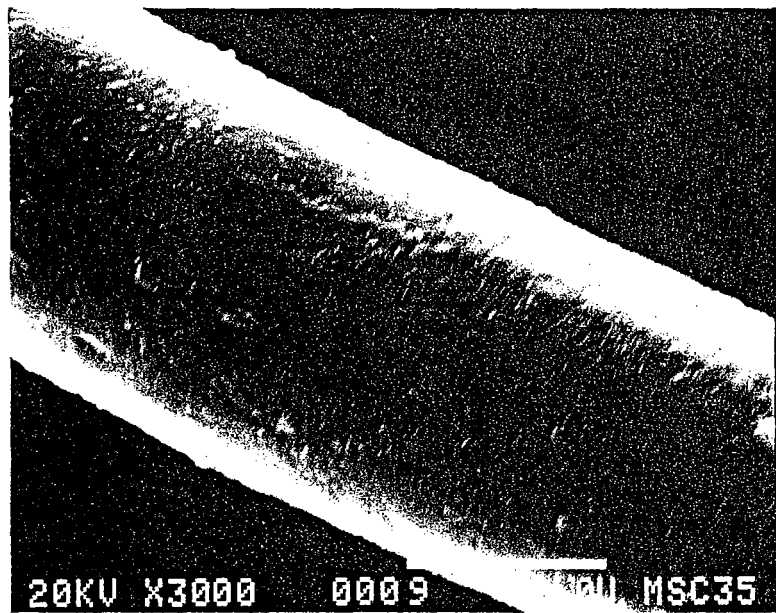


Fig. 15. SEM micrograph of PET/GT treated at pH 10 for 6 wks at 95°C.

water hydrolysis, however, occurs within the fiber and no evidence of aging is visible on the surface. Figures 13 and 14 show the unchanged fiber surface before and after aging in pH 3 solution. However, severe etching marks can be seen in Fig. 15 on the PET fibers treated under extreme alkaline conditions, causing some cracks to develop on the fiber surface.

3.2 PP/GT (Polypropylene)

3.2.1 Tensile test results

Cut strip tests were performed on the Instron for the polypropylene geotextile, PP/GT, under the same conditions explained earlier for PET/GT in Section 2.2. A typical load-elongation plot for untreated PP/GT is shown in Fig. 16. The three zones with stress/strain characteristics similar to those for PET/GT (see Fig. 1) can be ascertained. PP/GT, however, exhibits a lower elongation at break than PET/GT. This is attributed to greater fiber entanglements in PP/GT as a result of heavier needle-punching, as compared to the lightly needled PET/GT. The lower strength of polypropylene fiber combined with a lower weight of the geotextile results in a lower strength (13.09 kN/m) in the machine direction for PP/GT as compared to the polyester geotextile. The anisotropic nature of construction of the PP/GT results in a lower value of geotextile strength (11.70 kN/m) in the cross direction, indicating a greater amount of fibers being aligned in the machine direction than in the cross direction. Peak stress data obtained before and after aging for PP/GT in the machine direction is plotted in Figs 17, 18 and 19.

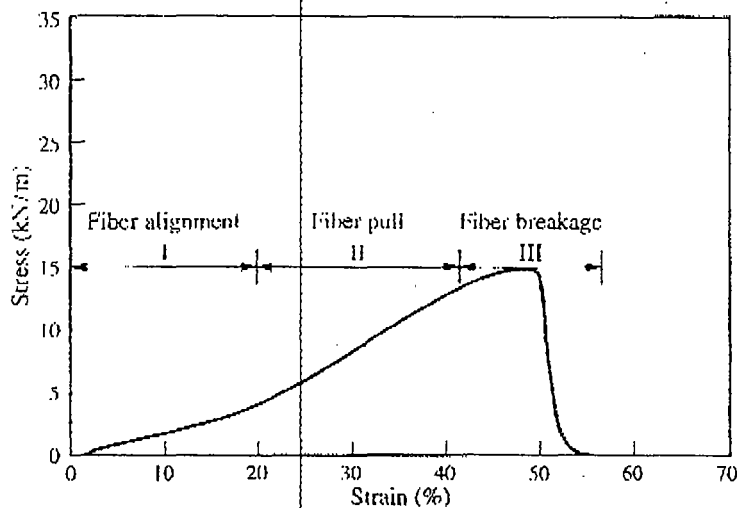


Fig. 16. Typical stress vs strain plot for PP/GT.

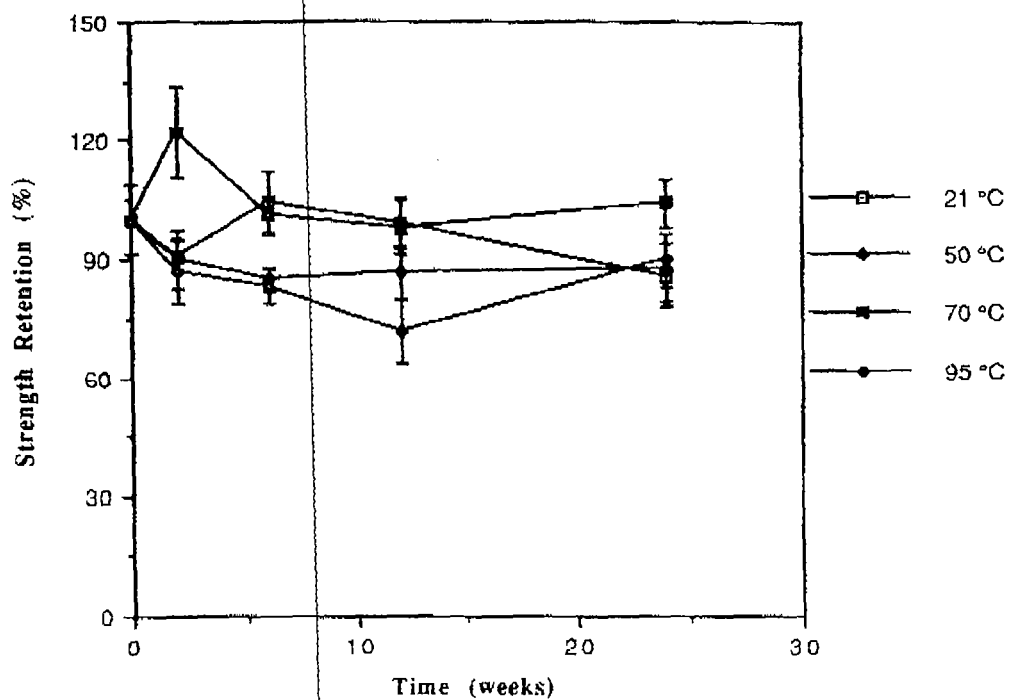


Fig. 17. Effect of pH 10 on PP/GT tensile strength.

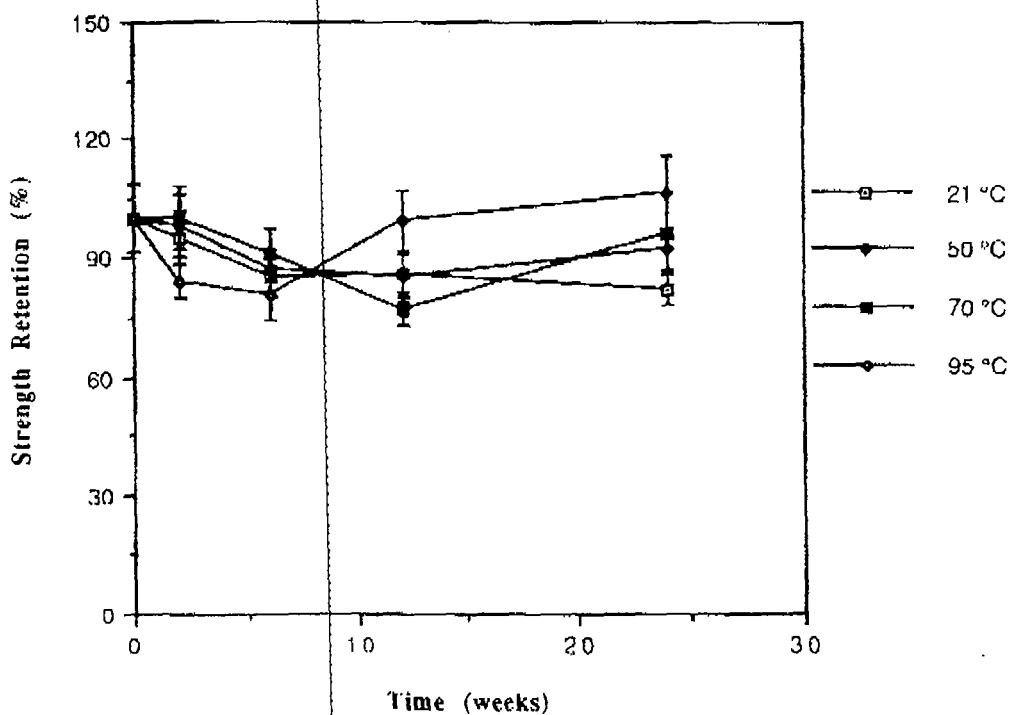


Fig. 18. Effect of pH 3 on PP/GT tensile strength.

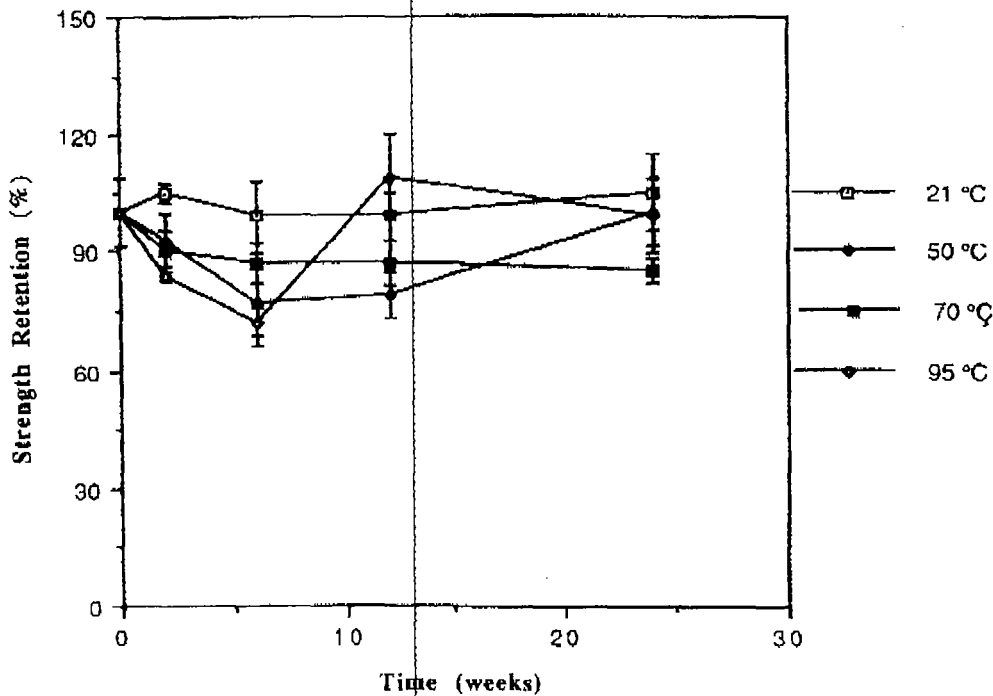


Fig. 19. Effect of sea water on PP/GT tensile strength.

In contrast to polyester, polypropylene fibers are made up of non-polar hydrocarbon chains which are relatively inert to chemical attack. No apparent strength loss occurred in PP/GT under any of the pH conditions, which agrees well with our expectations and the results obtained by earlier investigations (Halse *et al.*, 1987). All strength values were within one standard deviation of the strengths obtained with untreated PP/GT geotextiles. Even at the highest temperature of 95°C, the peak strength values in both machine and cross directions did not show any significant loss as compared to the untreated specimens. However, like polyester, the strain values of PP/GT decreased significantly in the machine and cross direction after 24 weeks of aging for all conditions. The brittleness occurred in the initial 6 weeks and then remained unchanged. Figures 20, 21 and 22 give the strain values obtained for the three pH conditions. As mentioned earlier, fiber tests could not be performed on PP/GT fibers because of difficulty in extracting fiber lengths required for testing.

3.2.2 DSC results: PP/GT

Polypropylene generally exists in its isotactic form in a fiber. The characteristic dual peak in the melting exotherm of this particular polypropylene geotextile is attributed to the slow solid phase transition from the γ (lower melting) form to the α (higher melting) form, which has time

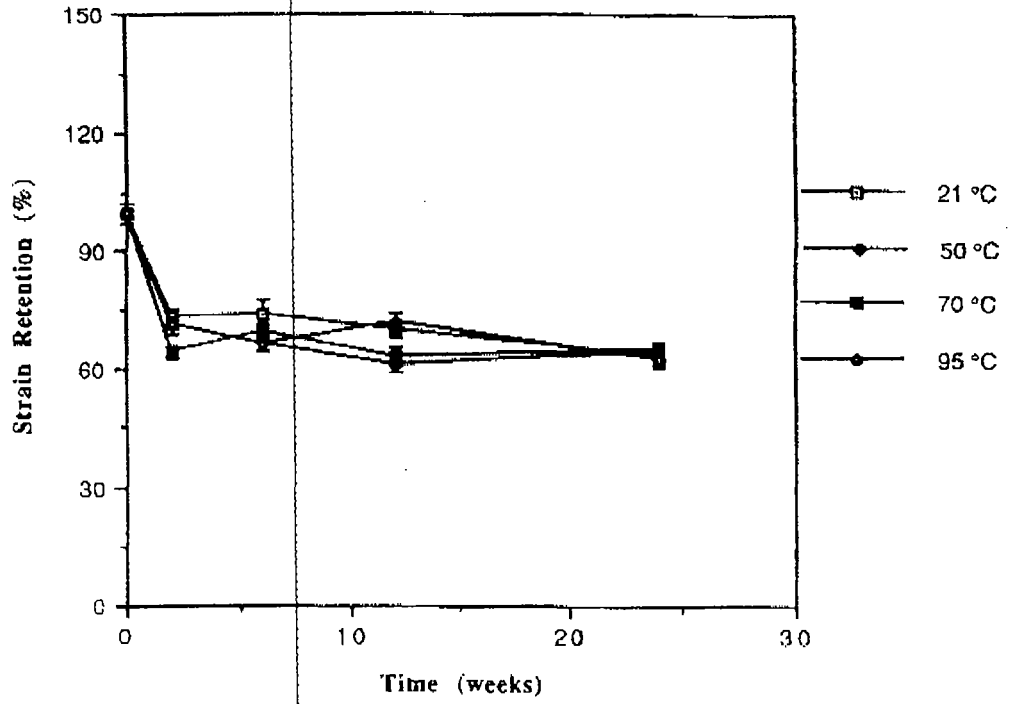


Fig. 20. Effect of pH 10 on PP/GT strain.

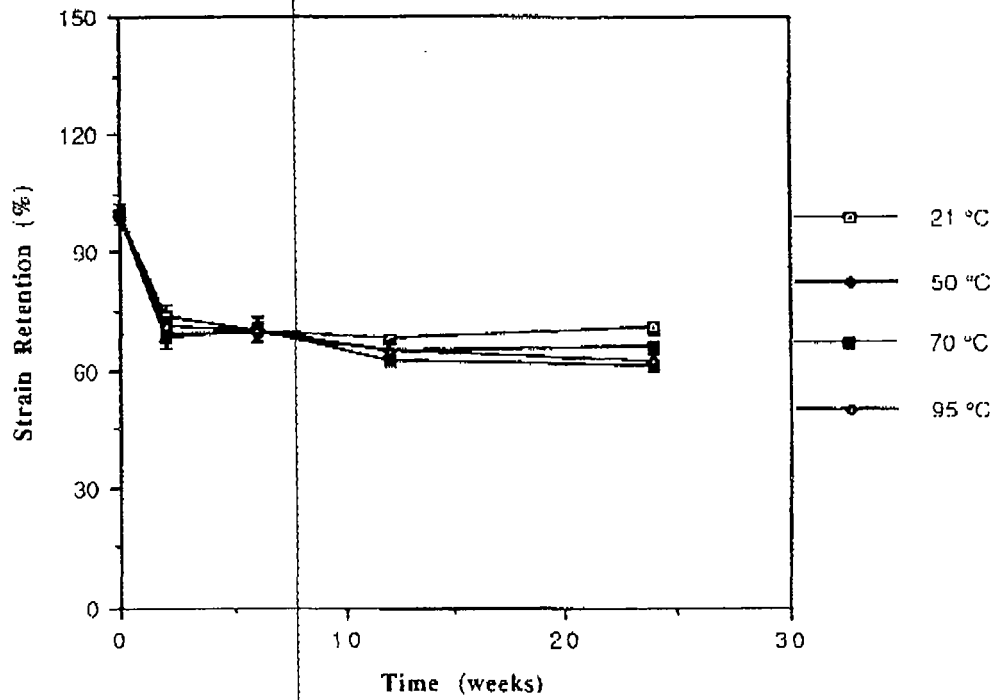


Fig. 21. Effect of pH 3 on PP/GT strain.

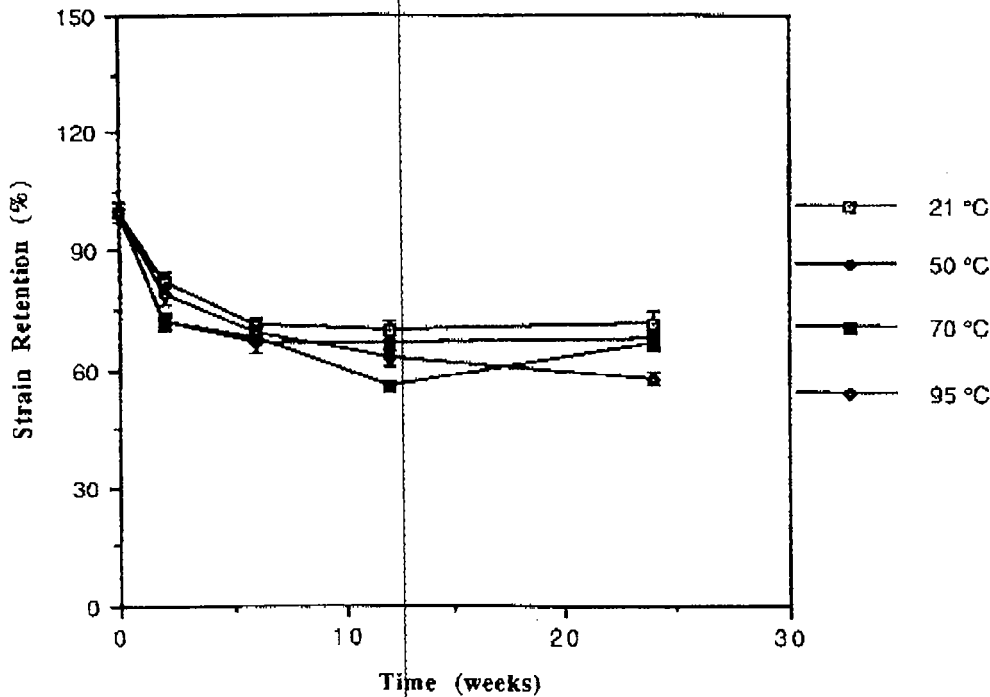


Fig. 22. Effect of sea water on PP/GT strain.

to crystallize during slow heating. Annealing the specimen just above the melting point of the γ form leads to conversion to the α form only. Figure 23 shows a typical DSC thermogram of PP/GT during the first heating run, clearly showing the two characteristic peaks. Figure 24 shows the thermogram for the second run corresponding to the annealing condition. In addition to the reasons discussed in Section 2.4, the second run was useful to maintain a constant thermal history and thus obtain the results under more controlled conditions. Also, because of the fast cooling, only one peak corresponding to the α form was observed which made it easy to compare the results of different aging conditions.

The melting point (T_m) for untreated polypropylene was found to be around 148°C, while the enthalpy of fusion (ΔH) was around 89-12 kJ/kg. Table 5 compares the values obtained for T_m and ΔH before and after aging for all pH conditions at 70°C and 95°C.

For all the three pH conditions, the DSC results follow the same trend. The T_m increases gradually from 148°C to 151°C, while ΔH gradually increases from 89 kJ/kg to 96 kJ/kg after 6 months (24 weeks) of aging, the effect being more pronounced at 95°C. The increase in both T_m as well as ΔH indicates an increase in both the crystallinity and crystal size. This may be attributed to effects of annealing at extended periods of time, wherein, molecular chains in the amorphous region get drawn out into crystalline domains. The reduction in the amorphous content is indicated

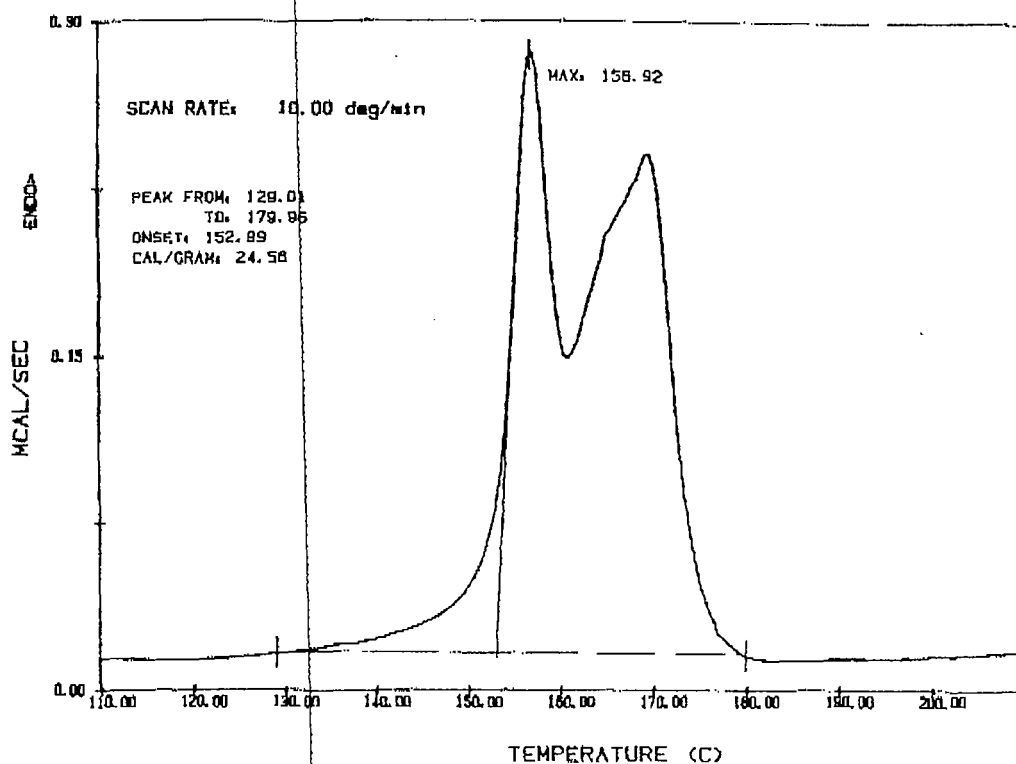


Fig. 23. Typical DSC thermogram of PP/GT (first run).

by slightly lower strains to failure after annealing. In other words, the whole system tends to equilibrate towards the lowest energy state, which is the crystalline state. This process is similar to the one for PFT/GT discussed earlier in Section 3.1.3. The increased crystallinity can be explained by studying the kinetics of the crystallization process. Nucleation and growth rates, and therefore the rate of crystallization, have been found to be sensitive to temperature (Ziabicki, 1976). At certain temperatures, these nucleation and growth rates pass through a maximum. For isotactic polypropylene, crystallization starts at around 30°C, passes through a maximum at around 65°C and drops off gradually after 95°C. In this study, PP/GT was subjected to temperatures ranging from 21°C to 95°C. These temperatures spanned the range of crystallization temperatures for polypropylene, thus promoting nucleation.

3.2.3 TGA results: PP/GT

Thermogravimetric analyzer results follow the same trend as observed for the DSC results. Figure 25 gives a typical trace of the thermogram obtained for the untreated PP/GT specimen. The onset of degradation for

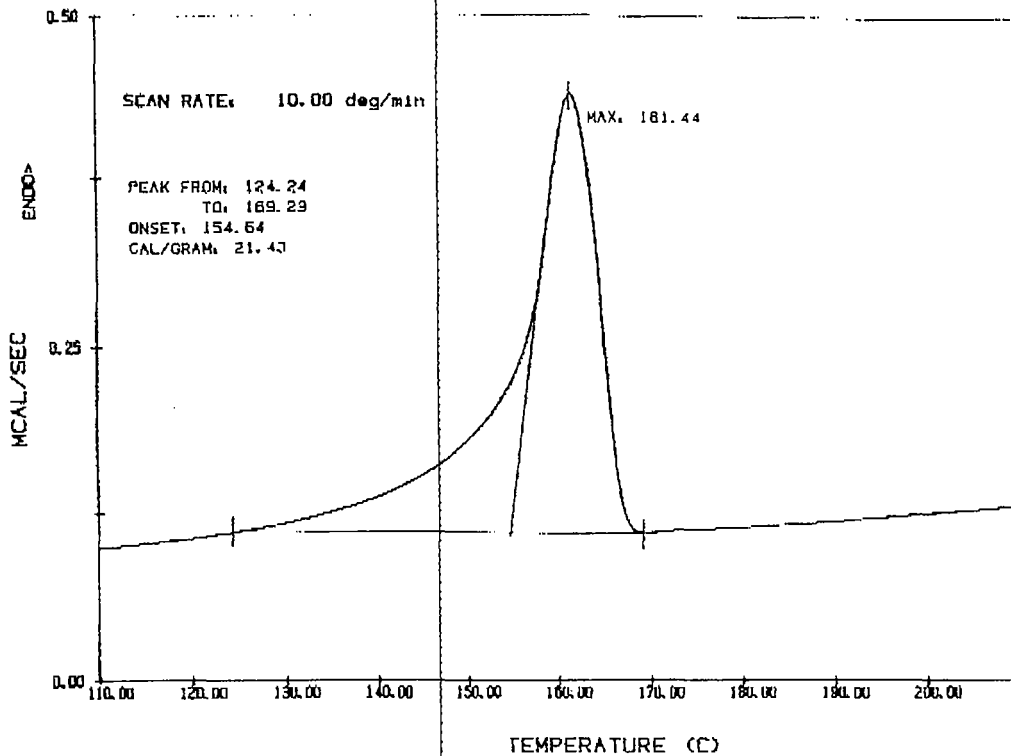


Fig. 24. Typical DSC thermogram of PP/GT (2nd run).

polypropylene at 462°C is higher than that for polyester, which agrees well with those obtained by Hsuan (1991). The absence of the oxygen in the PP structure renders it less prone to thermo-oxidative degradation as compared to PET, which has an ester group containing oxygen in its main chain.

Table 6 shows the results of the TG analysis for some extreme conditions. The degradation onset temperatures (T_d) are found to vary within a range of 459°C to 467°C for most of the cases.

3.2.4 Microstructure: PP/GT

SEM photomicrographs showing the effect of aging on the surface topology of the polypropylene fiber are shown in Figs 26 and 27. The surface of these fibers appeared relatively smooth even after the most intensive aging conditions. Unlike PET/GT, there is no evidence of etching marks or pitting of the surface. The surface features of PP/GT after 6 months of aging in pH 10, pH 3 and sea water appeared relatively smooth and similar to the untreated fiber. These observations confirm the relative inertness of polypropylene to chemical media, as determined from mechanical property testing.

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Table 5
DSC Results for PP/GT

| Temp | Untreated | 70°C | | 95°C | | | |
|-----------------------|-----------------|------------------|------------------|-----------------|-----------------|------------------|------------------|
| | | Time | 12 wks | 24 wks | 2 wks | 6 wks | 12 wks |
| <i>pH 10*</i> | | | | | | | |
| T_m (°C) | 148.0 (0.78) | 150.1 (0.65) | 150.9 (0.88) | 150.3 (0.89) | 150.9 (0.15) | 151.6 (0.99) | 151.2 (0.71) |
| ΔH (kJ/kg) | 89.12 (2.26) | 94.14 (4.06) | 102.09 (3.31) | 89.96 (3.51) | 96.23 (1.13) | 106.69 (7.45) | 103.34 (7.24) |
| <i>pH 3*</i> | | | | | | | |
| T_m (°C) | 148.0 (0.78) | 150.5 (0.87) | 150.0 (0.69) | 149.5 (1.00) | 149.1 (0.69) | 151.2 (0.21) | 151.2 (0.44) |
| ΔH (kJ/kg) | 89.12 (2.26) | 100.00 (4.31) | 104.60 (1.28) | 96.65 (1.97) | 92.88 (3.72) | 96.65 (6.32) | 104.18 (6.36) |
| <i>Sea water*</i> | | | | | | | |
| T_m (°C) | 148.0 (0.78) | 151.9 (0.78) | 150.7 (0.35) | 150.3 (0.47) | 150.4 (0.37) | 151.6 (0.47) | 152.6 (0.72) |
| ΔH (kJ/kg) | 89.12 (2.26) | 97.91 (2.34) | 97.06 (4.02) | 97.49 (4.35) | 94.56 (4.02) | 103.76 (5.40) | 105.86 (0.29) |

*Each reading is an average of 3 specimens with the standard deviations shown in parentheses.

4 ARRHENIUS MODEL: EXTRAPOLATION TO LONGER LIFE

Various predictive models, such as Arrhenius, Fyring and Inverse power models are currently used for extrapolating accelerated aging results to actual service conditions. The Arrhenius model, based on a time-temperature superposition principle is the most popular for polymer degradation and has the form

$$dr/dt = A \exp(-E_a/RT) \quad (2)$$

where dr/dt is the reduction of a material property with respect to time, E_a is the activation energy of the reaction, R is the universal gas constant, T is the absolute temperature and A is a material constant. The activation energy is the energy barrier which the reactants must surmount before going over into the reacted state and is characteristic of a reaction. Integration of the rate equation above, followed by taking logarithms, results in an equation of the form:

$$\ln t = (E_a/R) 1/T + B \quad (3)$$

where t is the time to reach a specified end-point and B an experimentally

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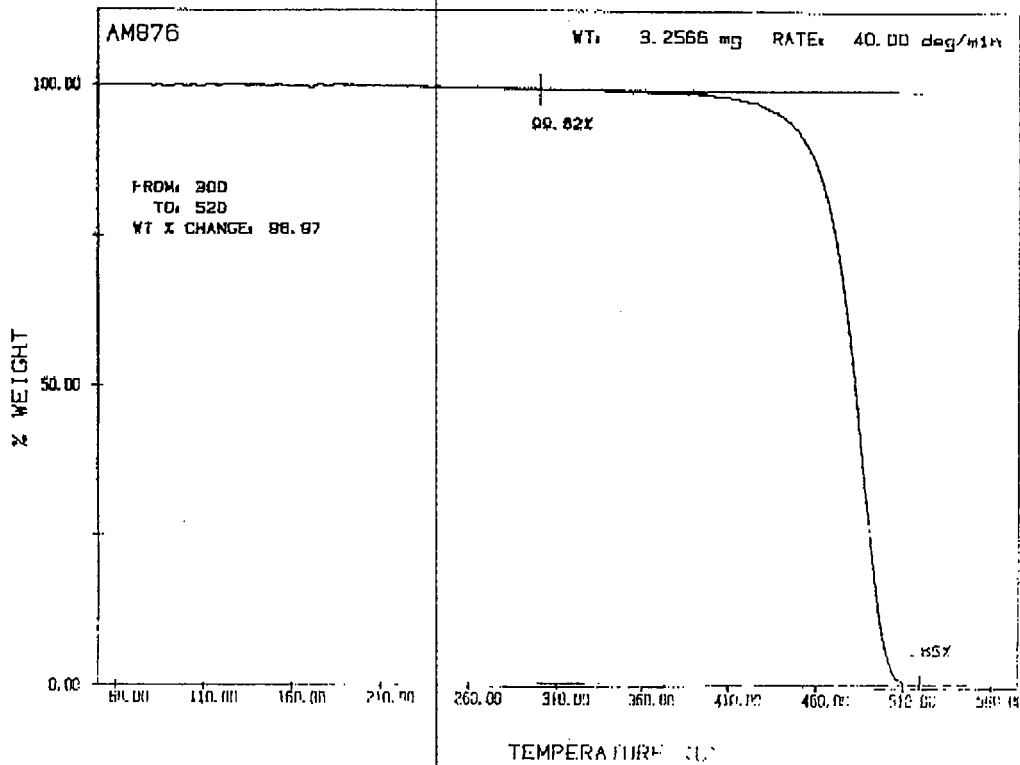


Fig. 25. Typical TGA curve for PP/GT.

Table 6
TGA Results for PP/GT

| Temp | 70°C | | | | 95°C | | |
|---------------------------|-----------|-------|--------|--------|-------|--------|--------|
| | Untreated | 6 wks | 12 wks | 24 wks | 6 wks | 12 wks | 24 wks |
| <i>T_d</i> (°C) | 462.8 | 461.0 | 458.7 | 463.2 | 464.2 | 463.6 | 464.2 |
| Wt. Loss (%) | 99.5 | 99.8 | 98.9 | 100 | 100 | 99.8 | 99.0 |
| <i>pH3*</i> | | | | | | | |
| <i>T_d</i> (°C) | 462.8 | 461.8 | 458.2 | 462.1 | 464.3 | 462.5 | 463.1 |
| Wt. Loss (%) | 99.5 | 99.7 | 99.8 | 99.5 | 97.9 | 99.0 | 99.3 |
| <i>Sea water*</i> | | | | | | | |
| <i>T_d</i> (°C) | 462.8 | 464.6 | 465.8 | 465.6 | 462.3 | 459.2 | 466.8 |
| Wt. Loss (%) | 99.5 | 99.2 | 99.6 | 99.4 | 99.7 | 98.6 | 96.3 |

*Each reading is an average of 3 specimens.

determined constant. A plot of $\ln t$ versus $1/T$ (Arrhenius plot) produces a straight line whose slope is E_a/R and has an intercept of B . This plot can then be used to extrapolate down to the service temperature of the material.

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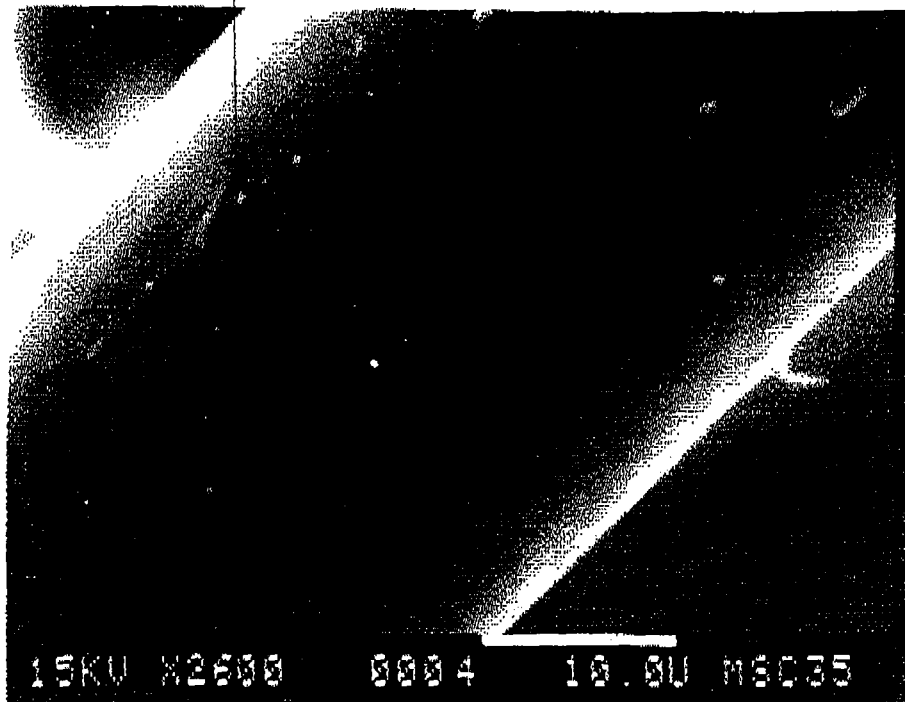


Fig. 26. SEM micrograph of untreated PP GF.

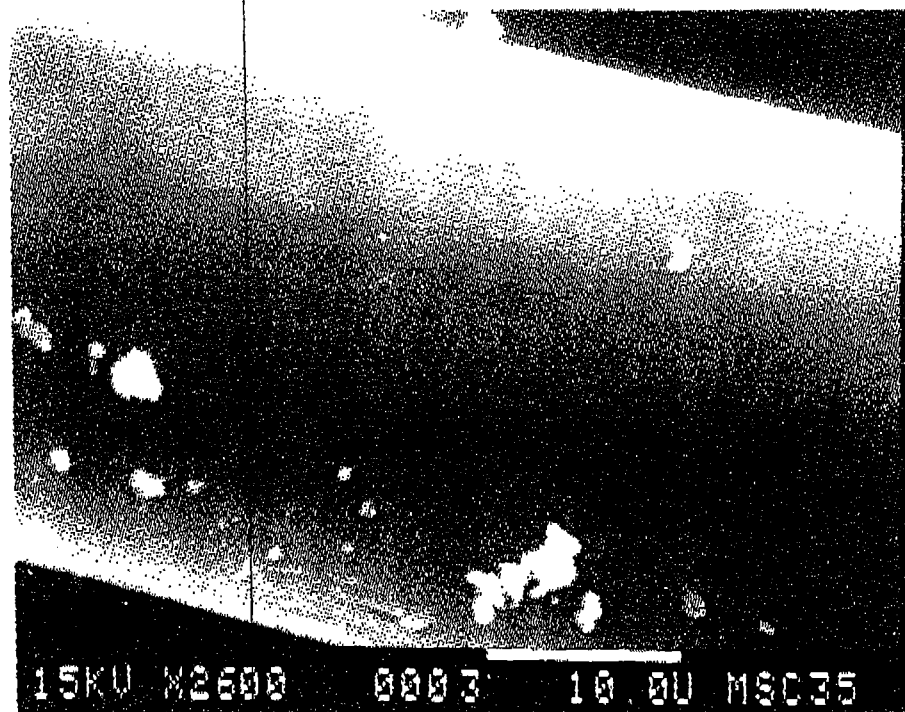


Fig. 27. SEM micrograph of PP GF treated at pH 3 for 24 wks at 95 C

It is argued that the reaction rate above the glass transition temperature may be different than below it and that a different mechanism operates at higher temperatures (Sotton & Leclercq, 1982). Results obtained by other researchers (McMahon *et al.*, 1959; Golike & Lasoski, 1960; Segrestin & Jailloux, 1988) however, do not indicate any erratic changes in the reaction rate.

McMahon *et al.* (1959) have reported activation energy values ranging between 100.4 and 121.3 kJ/mol for the hydrolysis of PET. Golike & Lasoski (1960) have reported a value of 94.6 kJ/mol, while Segrestin & Jailloux (1988) have used a value of 104.6 kJ/mol for life predictions of hydrolyzed polyester. In the degradation of polymers, it is not uncommon to observe a distribution of activation energies instead of a single activation energy. This reflects the multiplicity of 'reactions' that can lead to the final degraded products.

The selected endpoint is generally a property parameter of interest in the lifetime of the material. Koerner *et al.* (1992) have suggested the use of strength and elongation tests among 11 other candidate tests as a basis for Arrhenius modeling. The value selected as the endpoint differs from one application to another, and is generally taken to be lower than the original value. All calculations in the present study have been based on the selected endpoint of 90% of the original strength of the geotextile.

The changes in the peak strength of PET/GT with temperature and time for all the three pH values have been shown earlier in Figs 2, 3 and 4 in Section 3.1.1.1. As can be seen from these figures, the strength values at 21°C and 50°C are not significantly different from the untreated specimen values. The only significant changes (reduction) in strength are obtained at 70°C and 95°C. A similar trend was obtained for the peak strain results which are shown in Figs 5, 6 and 7.

The following assumptions are made for this model: (i) since the peak strength values obtained at 21°C and 50°C are not significantly different from the peak strength of the untreated specimen, they lie above the selected end point used for computation. Data obtained for these conditions are therefore not considered in the calculations; (ii) the reaction mechanism or the order of the reaction is the same at all the temperatures used, i.e. higher temperatures merely accelerate the rate of the degradation.

In addition, the data for all conditions have been fitted using best fit lines for ease in calculations. The activation energy (E_a) for the reaction is obtained either from the plot of $\ln(t)$ versus $1/T$ or by solving eqn (3) for the two temperature and time values. Table 7 shows the time to reach 90% of original strength at 70°C and 95°C for pH 10, 3 and sea water and the calculated activation energies.

Table 7
Activation Energy from Strength Results

| <i>pH</i> | <i>Temperature</i> (°C) | <i>Time</i> (weeks) | <i>Calculated</i> <i>activation energy</i> (kJ/mol) |
|-----------|----------------------------|------------------------|---|
| 10 | 70 | 13.00 | 123.01 |
| | 95 | 0.67 | |
| 3 | 70 | 17.50 | 95.81 |
| | 95 | 0.75 | |
| Sea water | 70 | 12.88 | 63.76 |
| | 95 | 2.81 | |

The values for the energy of activation for pH 10 and pH 3 treatments were found to vary between 96.23 and 125.52 kJ/mol. These values are in good agreement with the values obtained by other researchers (McMahon *et al.*, 1959; Golike & Lasoski, 1960; Segrestin & Jailloux, 1988). In the case of sea water, the uneven trend in the strength data made calculations difficult, and could therefore have led to erroneous results.

Koerner *et al.* (1992) have suggested that elongation may be a more sensitive parameter to assess polymer degradation than strength. Activation energies were therefore also determined using the Arrhenius model on the breaking strain data for the same conditions as above, the results of which are presented in Table 8. For these calculations, the endpoint selected was also 90% of the original strain.

The activation energy values obtained from strain results agree with those determined using strength values for pH 10 and pH 3. Figure 28 shows the Arrhenius plot obtained from the strain data. Extrapolation to service temperatures can be performed by substituting the E_a values in eqn (3) or by extending the Arrhenius plot to that temperature. It should be noted, however, that extrapolation would be more appropriate for temperatures higher than the glass transition temperature of PET/GT. Below the glass transition temperature, the activation energy value is expected to be higher.

5 CONCLUSIONS

The changes in the physical and mechanical properties resulting from accelerated chemical aging of two geotextiles, namely PET/GT (polyester) and PP/GT (polypropylene) were studied. The PP/GT (polypropylene) geotextile was stable for all pH, saline, and temperature conditions

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Table 8
Activation Energy from Strain Results

| pH | Temperature (°C) | Time (weeks) | Calculated activation energy (kJ/mol) |
|-----------|---------------------|-----------------|---|
| 10 | 70 | 19.60 | 130.54 |
| | 95 | 0.87 | |
| 3 | 70 | 21.15 | 108.57 |
| | 95 | 1.58 | |
| Sea water | 70 | 29.87 | 99.16 |
| | 95 | 2.79 | |

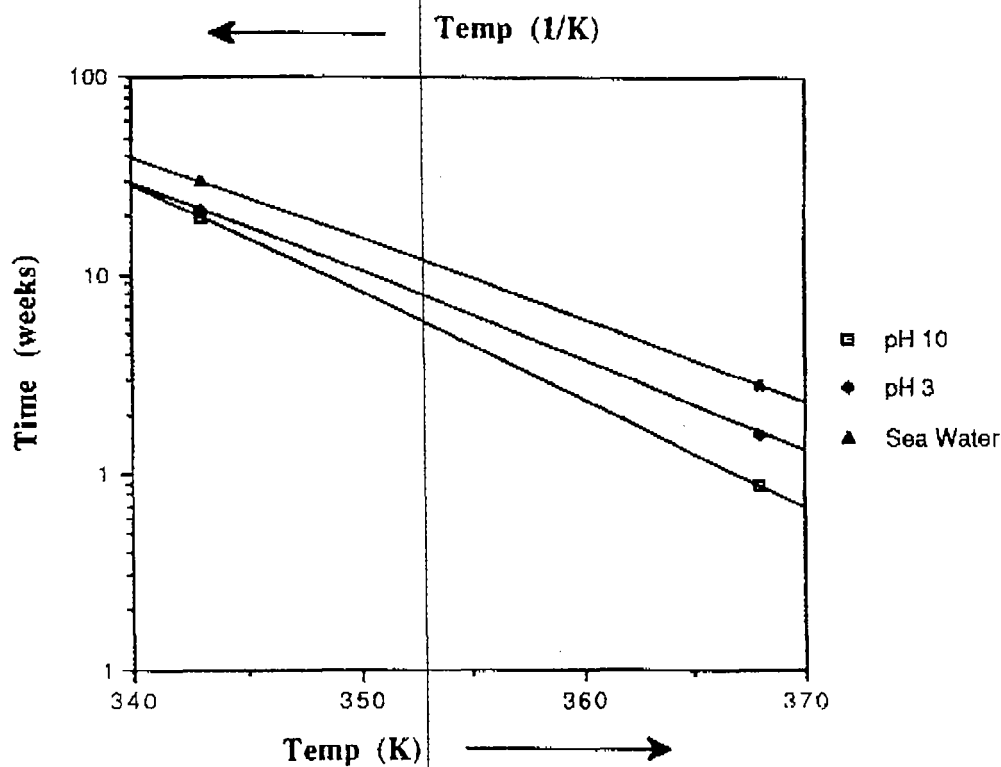


Fig. 28. Arrhenius plot for PET/GT using strain data.

studied, and showed no evidence of degradation. The polyester geotextile, on the other hand, underwent hydrolytic degradation at temperatures at and above the glass transition temperature. The extent of degradation was ascertained from the reduced tensile strengths for both the geotextile and fiber specimens, reduced elongation or increased brittleness, and the decrease in intrinsic viscosity. Importantly, for PET/GT, the decrease in breaking strength and strain was observed only at elevated temperatures

of 70°C and particularly at 95°C for relatively high and low pH. The Arrhenius model was fitted to the strength as well as the strain data to determine the activation energy of the degradation reactions, which can be used to extrapolate these results to actual service conditions. In practical terms, the energy of activation is low and implies that strength will be retained for substantial periods of time, even for rather severe pH environments.

Results from DSC analysis suggest an increase in the crystallinity for both polyester and polypropylene geotextiles during the initial period of aging. In the case of polyester, increased crystallinity was due to preferential attack on the amorphous regions and subsequent partial removal of the material. In polypropylene, this may have been the result of nucleation growth and lamellar thickening. The increased crystallinity implies that the geotextiles become stiffer with age. In a composite soil polymer structure, this stiffening may lead to a local concentration of stress in the geotextile, especially where continuing levels of deformation are imposed by the gradual accumulation of waste in a landfill or the underlying consolidation of soil along road courses and embankments. It is important to have a grasp of the variability inherent in materials and in the test methods before any predictions are made. It is hoped that the results of this study serve as a useful screening tool for geotextiles to be used in such applications.

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APPENDIX 12:
▪ **GEOTEXTILE INFORMATION**
ARTICLE ENTITLED: “AGING AND
DURABILITY OF POLYESTER
GEOTEXTILES”

AGING AND DURABILITY OF POLYESTER GEOTEXTILES

GERALD W. DAVIS
Technical Fibers Group
Hoechst Celanese Corporation
Charlotte, NC 28232

ABSTRACT

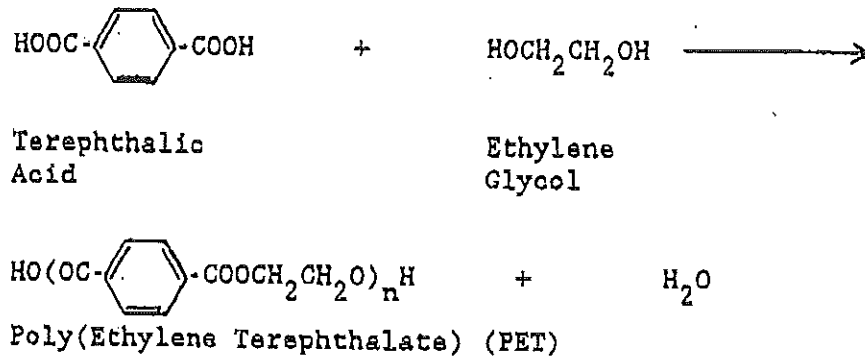
The general characteristics of the physical and chemical properties of polyester fibers and fabrics are reviewed in order to better understand general aging and durability features of polyester geotextiles. Key physical characteristics of polyester are excellent strength, toughness, abrasion, dimensional stability and thermal stability. Polyester also has excellent resistance to permanent deformation under load. Key chemical characteristics of polyester are low moisture regain and resistance to most chemicals encountered in soils; however, susceptibility of the ester group to hydrolysis may be a factor in some geotextile applications. In addition, polyester has good resistance to sunlight and excellent resistance to microorganisms in soils.

INTRODUCTION

Differences in physical and chemical properties of various geotextiles can be traced back to the fiber-forming polymers. Other factors include the methods by which the fiber and then the fabric are manufactured. In the case of geotextiles, the great versatility of polyester allows selective engineering at all the basic process steps - polymerization, fiber formation, and fabrication - to produce a broad range of products. Therefore, a brief introduction to "polyester" followed by a review of polyester fibers and fabrics will be presented.

DISCUSSION

When the term polyester fiber is used, it generally refers to poly (ethylene terephthalate) which has been shortened to PET in the trade. PET is the condensation homopolymer of terephthalic acid (or its dimethylester) and ethylene glycol.



PET is a long-chain linear polymer with typical number-average molecular weights of 15,000 to 30,000. The polymer is thermoplastic and may be converted to a fiber by melt spinning. Chemical functionality is derived from the ester group.

Manufacture

There are two major polyester processes (Figure 1) used to manufacture products for use in geotextiles; these are (1) the spunbond filament process for producing nonwoven fabrics and (2) the high tenacity filament process for yarns used in producing woven fabrics.

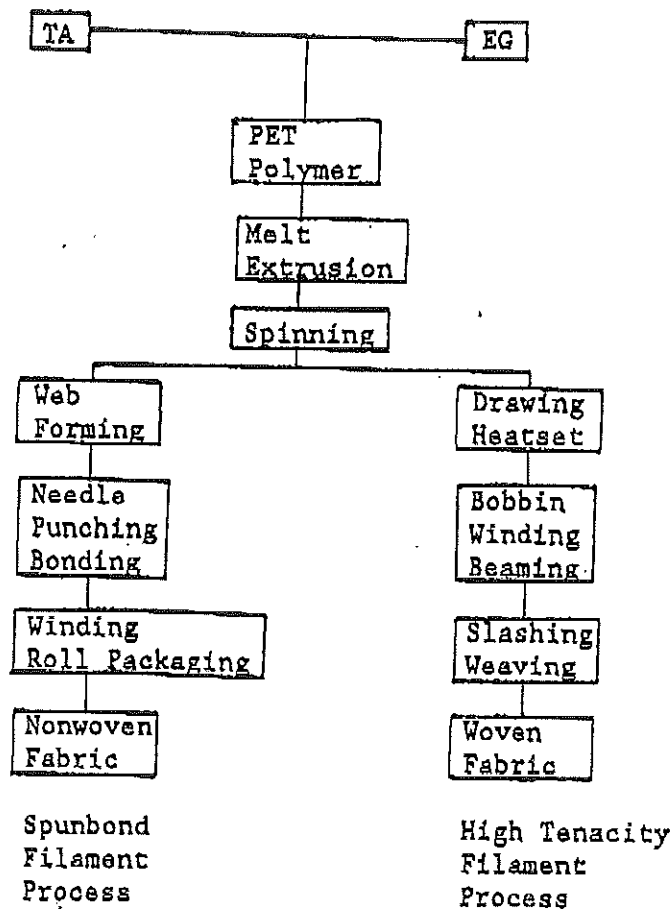


Figure 1. Polyester Fiber and Fabric Flow Diagrams

Terephthalic acid and ethylene glycol form a diester monomer which is polymerized to PET. The polymer is melted, extruded and spun through a spinneret with small holes, forming continuous filaments that are solidified by cooling in air. For spunbond fabrics, polymers with molecular weights of about 20,000 form these filaments which are laid down to form a web, then bonded, in this case by needle punching, to interlock the filaments to give the spunbond its characteristic tensile strength and dimensional stability. Chemical and thermal bonding can also be used. The formed fabric is then wound onto a core package and cut into standard lengths.

For high tenacity filament woven fabrics, the as-spun filaments, which are formed from about 30,000 molecular weight polymer, are drawn by heating and stretching them to several times their original length, followed by heatsetting to form an oriented semi-crystalline structure and impart the desired physical properties of high strength, toughness and dimensional stability. The treated filaments in yarn form are wound onto a bobbin, then rewound from many bobbins onto a beam for slashing, followed by weaving on a loom to the specified fabric.

Characteristics

The characteristics that account for the great versatility of polyester fibers are their high strength, high modulus, toughness, dimensional stability, low shrinkage, and heat-settability, low moisture regain and quick drying ability, thermal stability, and resistance to stretching and shrinking, most chemicals, abrasion, wrinkles, cuts, weather, and soil - all this with acceptable economics.

The enormous success of polyester in textile end uses such as apparel and home furnishings, in industrial end uses such as tires and roofing, and in carpet markets is attributed to these outstanding characteristics.

In the following sections, these characteristics will be discussed and, where possible, related to polyester geotextiles. Most of the data, unless specifically stated otherwise, has been taken from Trevira® polyester in-house studies.

Physical Properties

When discussing physical properties, the focus will be on those of polyester fibers and fabrics typically used in geotextiles. Certainly, a good place to start is to look at load bearing properties of polyester fabrics. With polyester, the two curves in Figure 2 illustrate, how fabrics can be selectively engineered to give very high strength and low elongation with wovens, or moderate strength and high elongation with needle punched nonwovens, plus quite a range of properties in between, to meet a variety of geotextile requirements.

Vivid examples of this flexibility can be seen by looking at the geotextile properties of different fabrics. In the case of polyester spunbond (Table 1), needle punched nonwoven fabrics of weights ranging from 3.5 to 16 oz/yd² yield a range of thickness from 60 to 210 mils, grab strength from about 100 to 600 lbs, puncture strength from 50 to 240 lbs, burst point from 180 to 840 psi, and various filtering capacities. Also, the thermal shrinkage of all these fabrics is only 2.9% at 400°C, the moisture regain is only 0.4%, and the specific gravity is 1.36.

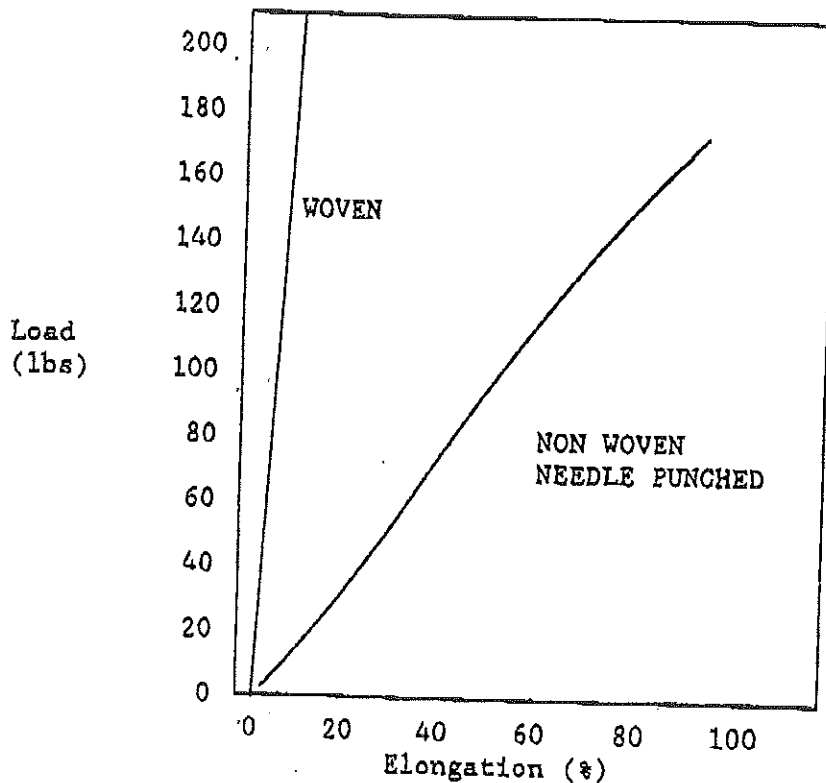


Figure 2. Load-Elongation Curves of PET Fabrics

TABLE 1
Geotextile Properties of PET Spunbond Fabrics

| | | |
|--|--------|---------|
| Weight, oz/yd ² | 3.5 | 16 |
| Thickness, mils | 60 | 210 |
| Grab tensile strength, lbs | 110/90 | 625/560 |
| Puncture strength force, lbs | 50 | 240 |
| Mullen burst point, psi | 180 | 840 |
| Trapezoid tear strength, lbs | 50/40 | 205/200 |
| Elongation at break, % | 70/85 | 90/95 |
| Permittivity, sec ⁻¹ | 2.04 | 0.75 |
| Normal permeability coefficient, cm/sec | 0.3 | 0.4 |
| Vertical water flow, gpm/ft ² | 150 | 55 |
| Apparent opening size, sieve size | 70-100 | 100-170 |
| Thermal shrinkage, % (400°C) | 2.9 | 2.9 |
| Moisture regain, % (65%RH, 72°F) | 0.4 | 0.4 |
| Specific gravity | 1.36 | 1.36 |

In the case of high tenacity polyester filament yarn (Table 2), fabrics may be woven in widths from tapes to sheets and may vary greatly in weights and thickness. This is accomplished by changing the denier (thickness) of the feeder yarns, the number of yarns in the warp and filling directions on the loom, and the pattern of the weave.

Table 2 lists some examples of commercial PET woven geotextiles with values obtained from published and promotional literature but with some values estimated [1]. These products offer a range of wide width tensile strength from 1000 lbs/inch in both the warp and fill direction up to 3790 and 1180 lbs/inch respectively in the warp and fill direction. The extension at failure conversely ranges from 15% to 11% for these fabrics. The important areas are strength and low elongation.

TABLE 2
Reinforcing PET Woven Geotextiles

| Product | Wide Width Tansile (lb/inch) | | Approximate Extension @ Failure (%) | |
|------------------------------------|---------------------------------|------|--|------|
| | Warp | Fill | Warp | Fill |
| Mirafi 2500HP | 1000 | 1000 | 15% | 15% |
| Exxon GTF2600T | 1600 | 1600 | 13% | 13% |
| Exxon GTF3200T | 3200 | 2400 | 13% | 13% |
| Nicolon New Orleans Test Fabric | 3790 | 1180 | 11% | 11% |

A typical polyester high tenacity filament yarn for this application has the following textile properties (Table 3): 1000 denier, 192 filaments, 5.2 dpf, almost 20 lbs breakload (which is around 9 gpd), and 13% elongation. Load at 5% elongation is about 10 lbs. It has excellent elastic recovery, stiffness (initial modulus) and toughness. Shrinkage is 6% in boiling water and 13.5% in 350°C air. As with spunbond, the moisture regain is 0.4% and specific gravity is slightly under 1.4.

TABLE 3
Textile Properties of PET High Tenacity Filament Yarn

| | |
|-----------------------------------|----------|
| Denier/Fils | 1000/192 |
| DPF | 5.2 |
| Breaking tenacity, gpd | 8.9 |
| Breakload, lbs | 19.8 |
| Load at 5% elongation, lbs | 10 |
| Breaking elongation, % | 13 |
| Elastic recovery at 5% elong, % | 90 |
| Initial modulus, gpd | 110 |
| Toughness, g cm | 0.7 |
| Moisture regain, % (65% RH, 72°F) | 0.4 |
| Specific gravity | 1.39 |
| Hot air shrinkage, % (350°F) | 13.5 |
| Boiling water shrinkage, % | 6 |

Creep

For a fabric to be dimensionally stable, it not only has to be stiff, have low stretch and shrinkage, but it should have good recovery properties. Elongation which occurs due to long-term loading versus instantaneous elongation is referred to as creep. Data in Figure 3 suggest that polyester can support a load over 50% of its breaking strength with minimal creep for an extended service life. This excellent creep resistance assures that loads employing polyester geotextiles remain secure for extended periods.

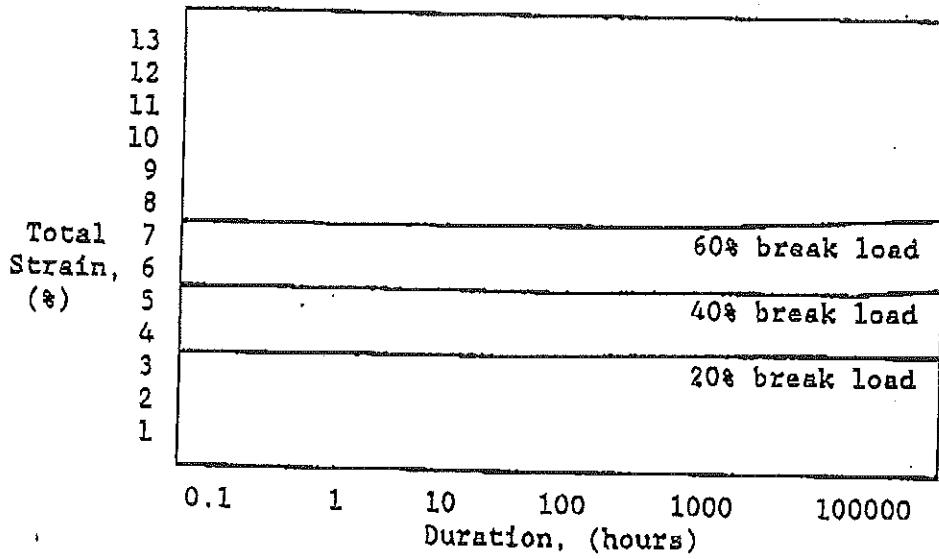


Figure 3. Creep Resistance of PET Fibers

Thermal Properties

Polyester fibers have outstanding thermal properties. They melt in the range of 478-490°F, soften at 440-445°F, crystallize at 250-265°F, have a glass transition temperature of 150-165°F - all well above normal conditions encountered in geotextile applications. In addition, polyester fibers maintain excellent flexibility and strength at temperatures below freezing.

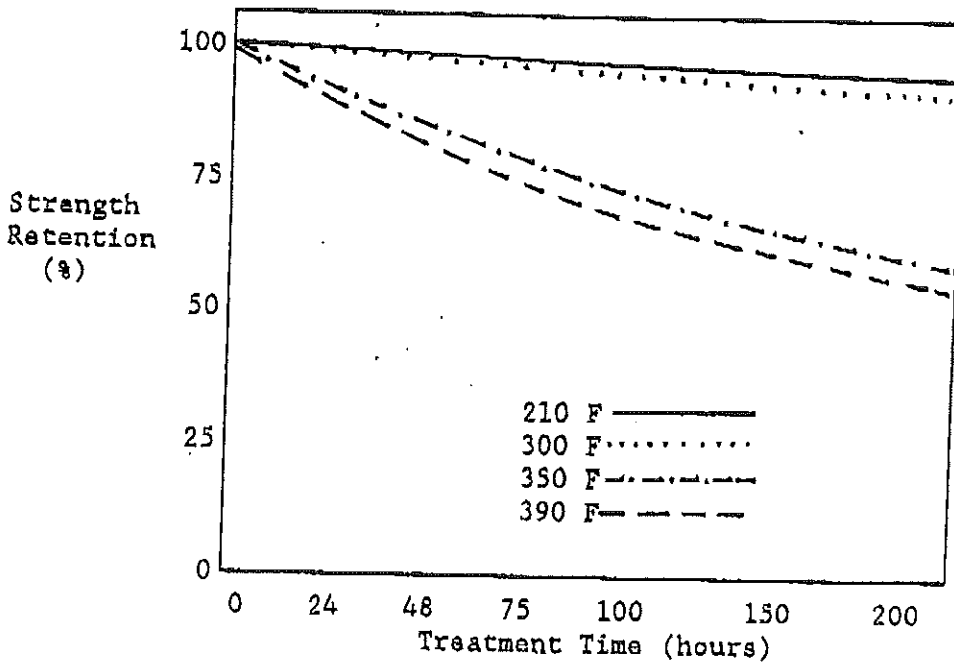


Figure 4. Thermal Resistance of PET Fibers.

The physical properties of most common fibers are affected by changes in temperature even in dry air. Some high temperature effects are temporary, provided that physical deterioration of the fiber does not occur. This is the case for polyester which has excellent thermal stability as shown in Figure 4. Prolonged exposure to very high temperatures, i.e., above 200°F, can result in thermal degradation and permanent strength loss. However, even at temperatures approaching 400°F, over half the strength is retained for several days.

Chemical Resistance

Another property critical to geotextile performance in some application is chemical resistance. On this matter, an appreciation of the very diverse uses for polyester materials is realized. Users frequently want to know what polyester will do in various environments. These range from sodium ammonium hydrogen phosphate, to moist NPK fertilizer, to apoxidized soy bean oil.

Fortunately, many diverse environments have been tested and the results are available. A review of some of that data with the intent of showing general resistance to classes of chemicals as well as the effects of temperature, time and concentration in select cases follows. It is more important to be aware of the type of information available, to realize that generalizations aren't always appropriate, and to understand that discussion and even a study may be the best way to proceed when considering the use of any synthetic geotextile in a new environment.

Generally speaking however, polyester geotextiles have excellent stability to many chemical classes such as water, salts, organic acids, organic solvents, dry cleaning solvents, oxidizing agents (bleaches), reducing agents, gases and fuels (petroleum). They are susceptible, under certain conditions, to chemical classes such as inorganic acids, halogenated organic acids, inorganic and organic bases, benzyl alcohol, and halogenated phenols, while the effects of leachates and "buffered solutions" are dependent on their chemical composition (Table 4).

TABLE 4
Chemical Resistance of PET Geotextiles

| | |
|-----------------------------|-----------------------|
| Water | Excellent |
| Salts | Excellent |
| Organic Acids | Excellent |
| Organic Solvents | Excellent |
| Dry Cleaning Solvents | Excellent |
| Oxidizing Agents (Bleaches) | Excellent |
| Reducing Agents | Excellent |
| Gases | Excellent |
| Fuels (Petroleum) | Excellent |
| Buffered Solutions | Good |
| Leachates | Composition Dependent |
| Inorganic Acids | Catalyzed Hydrolysis |
| Halogenated Organic Acids | Dissolves |
| Inorganic Bases | Hydrolysis |
| Organic Bases | Aminolysis |
| Benzyl Alcohol | Dissolves |
| Halogenated Phenols | Dissolves |

Water Stability

This leads to the effects of rain, seawater or other forms of water on polyester. There isn't much to discuss since polyester is virtually unaffected by water.

Polyester's resistance to the effects of water is easily explained. As shown in Figure 5, moisture absorption of polyester is only 0.4% at room temperature and 65% relative humidity. Even at 95% humidity, less than 0.6% moisture is absorbed. Because of its low moisture absorption, polyester geotextiles will not get heavy when wet, will not mildew, and will dry very quickly. Most importantly, polyester's strength is unaffected by water under normal conditions.

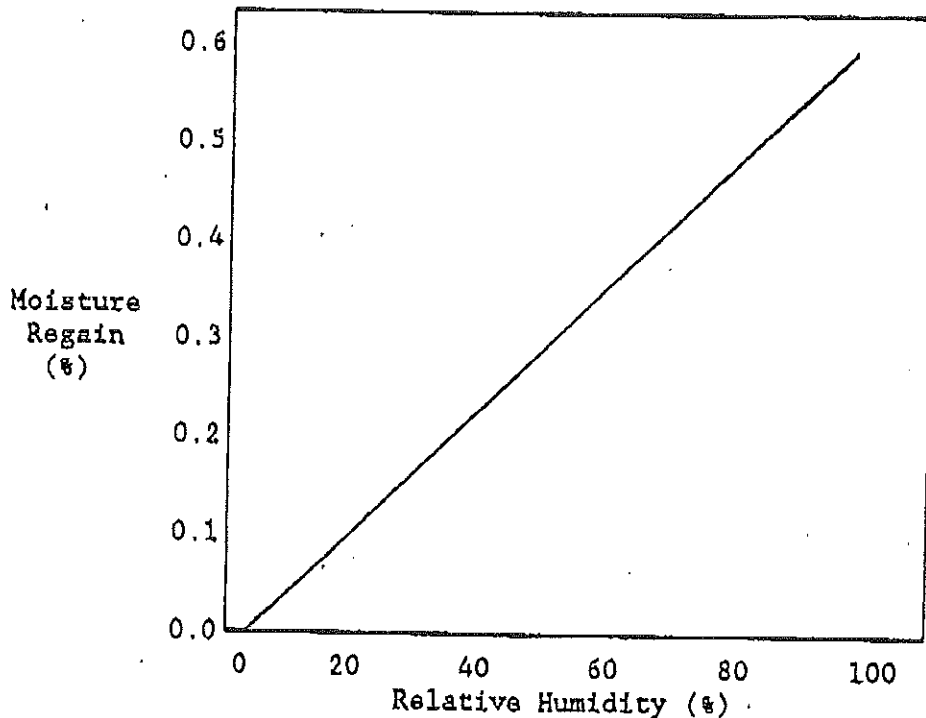


Figure 5. Moisture Regain of PET Fibers at 70°F.

Polyester's strength in water over 40 days at room temperature is unchanged and at 122°F, 94% of polyester's original strength is maintained (Figure 6). The effect of higher temperature such as steam shows accelerated strength loss.

The wet mechanical properties of polyester geotextiles are the same as dry. There is no strength loss as mentioned earlier; stretch to break (elongation) is not affected; there is no change in abrasion resistance; and there is no growth or shrinkage (i.e., elasticity is not affected).

Polyester fibers can be plasticized by water, but this plasticization is very slow. The water enters the amorphous regions of the polymer and enhances molecular mobility. The result is a small loss in modulus and strength, but the effect is completely reversible when the water is removed.

PET fibers are only affected by water if conditions are such that hydrolysis of the ester group takes place. This is a very slow process at ambient conditions. The rate of hydrolysis is dependent on temperature and is most sensitive to acid and base conditions which can catalyze the hydrolysis reaction.

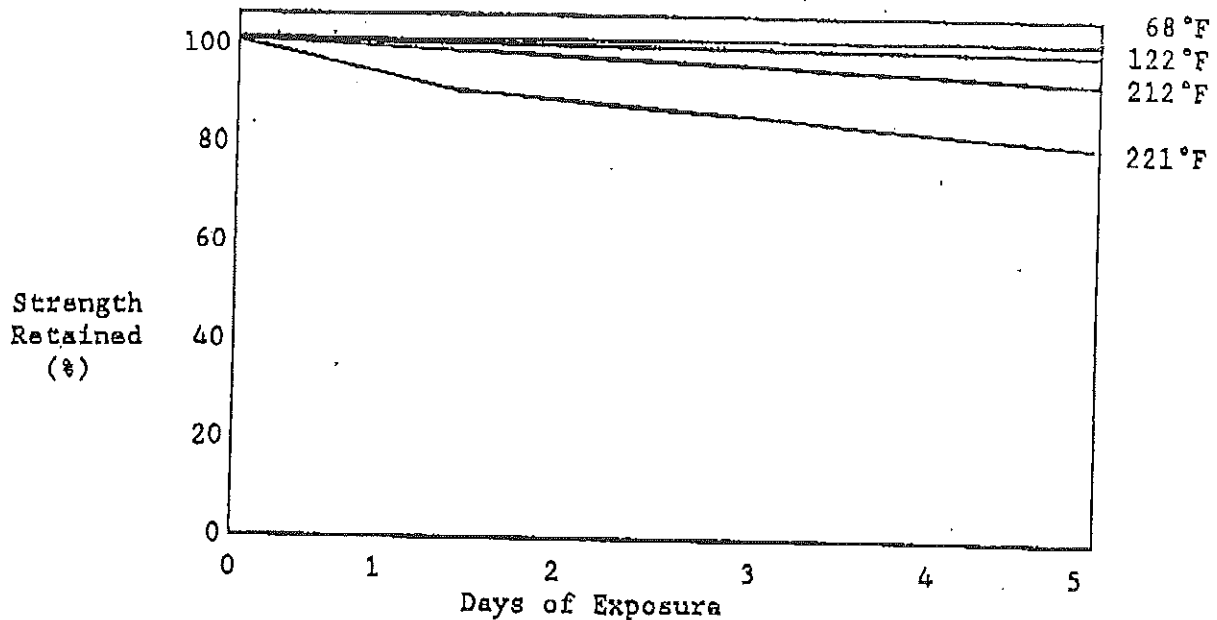


Figure 6. Strength Retention of Polyester in Water and in Saturated Steam

Once again, the very low moisture absorption level leads to significantly reduced weight gain and yields fabrics which dry quickly. Polyester's ability to maintain strength and dimensional stability in water therefore makes it an excellent candidate for geotextile applications.

Acid Resistance

Moving on to acids, their effect on polyester is a mixed bag of results. Polyester is highly resistant to most mineral and organic acids. Some of them (formic, nitric, 20% hydrochloric, battery acid) are quite strong but still have no effect on polyester after a one-year exposure as shown in Table 5. Polyester's long term resistance to sulfuric acid makes it excellent for use in acid rain conditions, which become more severe each year.

TABLE 5
Acid Resistance of PET Geotextiles

| Compound | pH | % Strength Retained After one year at 70°F |
|-------------------------|-----|---|
| Acetic, conc. | 0.1 | 100 |
| Benzoic | - | 100 |
| Boric | 3.5 | 100 |
| Chlorosulfonic | - | Degraded |
| Citric, 25% | 1.2 | 100 |
| Formic, conc. | 0.1 | 100 |
| Hydrochloric, 15% | 0.1 | 100 |
| Hydrochloric, 20% | 0.1 | 100 |
| Hydrofluoric, 10% | - | Degraded |
| Lactic, conc. | 0.7 | 100 |
| Nitric, 15% | 0.1 | 100 |
| Phosphoric, 20% | 0.6 | Degraded |
| Sulfuric, 38% (Battery) | 0.1 | 100 |

While polyester is highly resistant to most acids, it is affected by high concentrations of some very strong acids. In most cases however, even these strong acids have little or no effect on polyester after one month. However, chlorosulfonic acid destroys polyester immediately: an example of the danger of generalizing.

Just as dry and wet heat have an effect on polyester, acids at increasing temperatures have a deleterious effect as well. Whereas at room temperature, original strength is maintained even in high acid concentrations, high temperature exposures decompose polyester even at low concentrations.

Also, generalizations are not always appropriate when looking at the effect of pH on acid degradation. In some conditions, polyester can withstand pH's below 0.1. Acid catalyzed hydrolysis is the more important mechanism, thus environmental conditions must be known before determining the role of acids on polyester geotextile durability.

Alkaline Resistance

In contrast to excellent acid resistance, polyester has somewhat limited resistance to alkalis as shown in Table 6. These include ammonia media and caustic solutions of relatively high concentration. However, again, generalizations aren't always appropriate. For example, one month exposures to ammonia, up to 50% concentrated calcium hydroxide, and to several other alkaline solutions have no effect on the strength of polyester. In fact, some alkalis only slightly affect polyester even after one year of exposure. Once again, discussion and even a study may be required before deciding on the material for a specific geotextile application.

TABLE 6
Alkaline Resistance of PET Geotextiles

| Compound | pH | % Strength Retained After One Year (70 °F) |
|---------------------------|------|--|
| Ammonium hydroxide | 8-10 | 88 |
| Ammonium hydroxide, 2% | 11.4 | SD* |
| Calcium hydroxide, 15% | 12.4 | SD |
| Diethylamine | 3.5 | SD |
| Hydrazine, 2% | 10.6 | 76 |
| Hydrazine, 5% | 10.8 | SD |
| Potassium hydroxide, 0.1% | 12.5 | 90 |
| Potassium hydroxide, 2% | 13.4 | SD |
| Sodium hydroxide, 0.1% | 12.1 | 94 |
| Sodium hydroxide, 2% | 12.8 | SD |
| Triethanolamine | 13.3 | 66 |
| Urea | 10.4 | 91 |

*Severely Degraded.

As in the case of acids, alkaline degradation increases with higher temperatures, higher concentrations and longer exposure times.

Polyester is particularly sensitive to ammonia, hydrazine and organic bases such as amines. These chemical compounds penetrate the structure through noncrystalline regions, causing degradation of the ester linkage.

Two mechanisms are involved: (a) alkaline hydrolysis in which the hydroxide nucleophile attacks the ester groups at its surface, etching the fiber and (b) nucleophilic amidation by amines which penetrate the fiber. Also, as with acid, the effect of pH on alkaline degradation should not be generalized. pH detects hydroxide ions, but doesn't determine the strength of nucleophiles, therefore strength loss in some cases at pH's above 12 is small. Conditions must be known before determining the effect of alkali on polyester geotextiles.

Inorganic Salt Resistance

Aside from its susceptibility to acid catalyzed hydrolysis and selective nucleophilysis, polyester is resistant to most other chemicals. These include a wide range of inorganic (and organic salts as well) which do not affect polyester after a full year of exposure (Table 7). A few exceptions are salts like sodium bisulfite and ammonium sulfide which form deleterious hydronium ions and ammonia. Again, pH is not necessarily a determining factor.

TABLE 7
Inorganic Salt Resistance of PET Geotextiles

No strength loss after one year at 70°F

| <u>Compound</u> | <u>pH</u> | <u>Compound</u> | <u>pH</u> |
|----------------------|-----------|--------------------|-----------|
| Aluminum sulfate | 2.9 | Potassium | |
| Ammonium chloride | 5.1 | perchlorate | 9.9 |
| Ammonium nitrate | 4.8 | Potassium | |
| Ammonium sulfate | 4.6 | permanganate | 9.7 |
| Calcium chloride | 7.2 | Potassium sulfate | 7.5 |
| Calcium nitrate | 3.9 | Silver nitrate | 4.6 |
| Copper sulfate | 3.5 | Sodium ammonium | |
| Ferric chloride | 0.8 | hydrogen sulfate | 8.2 |
| Ferrous sulfate | 3.0 | Sodium bicarbonate | 7.8 |
| Magnesium chloride | 4.0 | Sodium carbonate | 11.2 |
| Magnesium sulfate | 6.6 | Sodium chlorate | 7.4 |
| Nickel sulfate | 6.6 | Sodium chloride | 7.4 |
| Potassium bichromate | 3.7 | Sodium nitrate | 8.3 |
| Potassium bromide | 6.5 | Sodium perchlorate | 5.8 |
| Potassium carbonate | 13.1 | Sodium sulfate | 5.4 |
| Potassium chlorate | 6.9 | Sodium tetraborate | 9.3 |
| Potassium chloride | 8.0 | Sodium thiosulfate | 5.4 |
| Potassium chromate | 9.4 | Zinc chloride | 2.4 |
| Potassium nitrate | 8.8 | Zinc sulfate | 4.0 |

Strength Loss

| | |
|------------------|----------------------------------|
| Sodium bisulfite | 4.1 (94% after one year) |
| Ammonium sulfide | 9.6 (Destroyed after six months) |

Organic Solvent Resistance

Polyester is insoluble in most organic solvents except for some polyhalogenated acetic acids and phenols. The list (Table 8) is very long for organic solvents, including commonly used organic chemicals, fuels and plasticizers, which do not effect polyester strength after a full year of exposure.

There are exceptions of course, such as benzyl alcohol, alkyl amines (especially primary), and, to a small extent, tetrachloroethane.

TABLE 8
Organic Solvent Resistance of PET Geotextiles

No strength loss after one year at 70°F

| | |
|----------------------|----------------------|
| Acetone | Hydroquinone |
| Amyl acetate | Isopropyl alcohol |
| Aniline | Isooctane |
| Asphalt | Jet propellant |
| Benzaldehyde | Methyl acetate |
| Benzene | Methyl alcohol |
| Butanol | Methylene chloride |
| Butyl acetate | Methyl ethyl ketone |
| Carbon tetrachloride | Mineral oil |
| Chloroform | Nitrobenzene |
| m-Cresol | Phenol |
| Cyclohexanone | m-Phenylene diamine |
| Diesel Fuel | 2-Phenylethylalcohol |
| Dimethyl formamide | Pyridine |
| Dimethyl sulfoxide | Resorcinol |
| Epichlorohydrin | Styrene |
| Ethanol | Toluene |
| Ether | Trichloroethylene |
| Ethyl acetate | Trimethylamine |
| Formaldehyde, 30% | Turpentine |
| Formamide | White spirit |
| Gasoline | Xylene |
| Glycol | |

Strength Loss

Benzyl alcohol (Dissolved)
Alkyl amines (Degraded)
Tetrachloroethane (92% after one year)

Environmental Resistance

Moving on to more practical considerations for geotextiles, polyester's durability in most environmental conditions is quite good. This is especially true for normal weather with respect to rain, heat, sunlight and radiation (Table 9). The water and heat resistance has already been discussed. Sunlight (or ultraviolet) resistance is a more controversial area, since untreated polyester can experience slow ultraviolet degradation. Polyester properties are not affected by moderate doses of high energy radiation.

TABLE 9
Weather Resistance of PET Geotextiles

| | |
|-----------|-----------------------|
| Rain | Excellent |
| Heat | Excellent |
| Sunlight | Slow U.V. Degradation |
| Radiation | Excellent |

In the case of soil exposure, polyester durability to moisture, microorganisms, dry fertilizers, dry concrete, asphalt, and bitumen is excellent (Table 10). However, fertilizers can attack polyester under certain moist conditions. Research on concrete in moist conditions is underway.

TABLE 10
Soil Resistance of PET Geotextiles

| | |
|----------------|-----------------------|
| Moisture | Excellent |
| Microorganisms | Excellent |
| Fertilizers | Moisture Dependent |
| Concrete | Under Study |
| Asphalt | Excellent |
| Bitumen | Excellent |
| Leachates | Composition Dependent |

Sunlight Resistance

For up to 400 hours of direct sunlight (two-six months aging in calendar time), untreated polyester will retain greater than 90% of its strength (Figure 7). Longer term, the ultraviolet degradation slows down and can level out. Half the strength remains after 4000-5000 hours. Actual levels of deterioration vary depending on the number of sunlight hours and sunlight intensity which vary each year and depend greatly on geographic location and climatic conditions. For this reason, such conditions should be considered in any prediction of the effects of sunlight on any organic material.

Further, note that polyester is only sensitive to the ultraviolet region between 3000 and 3300 angstroms. It is very easy to block these rays, allowing a long life, with no effect on strength. In fact, the outer layers of the fabric itself have the ability to filter these rays from inner layers. Therefore, deterioration in thick, heavy fabrics is slight relative to that in yarn. This accounts for the leveling effect over time as shown in Figure 7.

Soil Resistance

The strength retention of polyester is highly dependant on soil conditions as stated earlier. Based on one study of high tenacity woven fabrics encapsulated in pH 5.8-6.3 soil in Frankfurt, W. Germany, the degree of deterioration lessens each year through the first five years, with 85% strength retained after this period (Figure 8). Furthermore, it was concluded that the deterioration in the first five years was not chemical but rather caused by physical damage during installations and removals.

In an independent study by G. Colin and co-workers (2) polyester nonwoven fabrics buried in soil for seven years showed no significant decrease in bursting strength. Soil burial exposure was carried out in a moist, organically rich soil maintained at 86°F and 85-90% relative humidity.

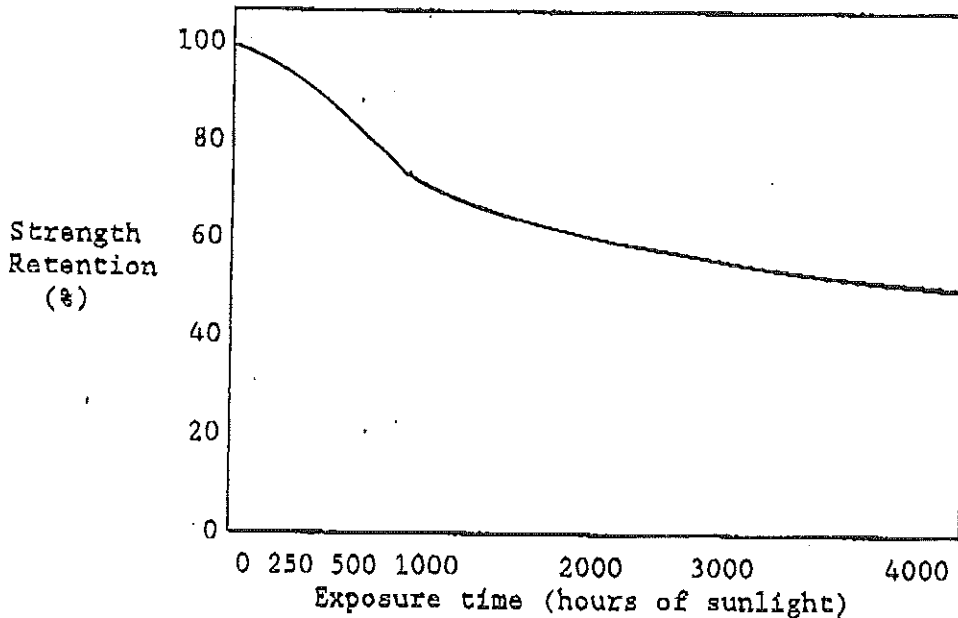


Figure 7. Resistance of PET Fibers to Direct Sunlight Exposure

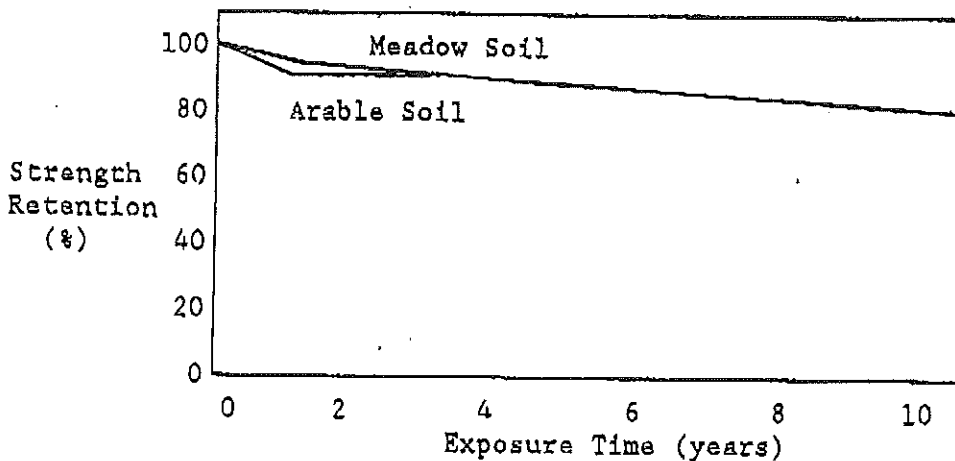


Figure 8. Strength Retention of Woven PET Fabric After Soil Encapsulation (pH 5.8-6.3)

Fertilizer Resistance

As mentioned, the effect of fertilizer on polyester is dependent on both the chemical composition and the moisture content of the fertilizer (Table 11). Materials which form acids or bases can lead to varying amounts of hydrolytic degradation.

TABLE 11
Resistance of Polyester to Fertilizers

| | <u>Degradation</u> | |
|-------------------------|--------------------|------------------|
| | <u>1 Month</u> | <u>12 Months</u> |
| Ammonium Nitrate | None | None |
| Ammonium Sulphate | None | Slight |
| Calcium Nitrate | None | None |
| Calcium Cyanamide, Dry | None | None |
| Calcium Cyanamide, Wet | None | Degraded |
| Lime, Slaked | None | Slight |
| Lime, Slaked, Moist 50% | None | Destroyed |
| NPK | None | Slight |
| Thomas Mead | None | Slight |
| Thomas Mead, Moist 50% | Slight | Appreciable |
| Urea | None | None |

Leachate Resistance

Leachate is generated as a result of liquid flowing through the soil, forming solutions of both dissolved and suspended materials. The composition of the leachate is highly dependent on the soil and weather conditions and is difficult to predict since there are so many variables which affect this solubilization of organic and inorganic constituents. The range and level of leachate however is generally highest in solid waste landfills as shown in Table 12.

TABLE 12
Composition of Typical Leachate [3]

| <u>Constituent</u> | <u>VALUE mg/L</u> | |
|------------------------|-------------------|----------------|
| | <u>Range</u> | <u>Typical</u> |
| BOD ⁵ | 2,000 - 30,000 | 10,000 |
| TOC ⁵ | 1,500 - 20,000 | 6,000 |
| COD | 3,000 - 45,000 | 18,000 |
| Total Suspended Solids | 200 - 1,000 | 500 |
| Organic Nitrogen | 10 - 600 | 200 |
| Ammonia Nitrogen | 10 - 800 | 200 |
| Nitrate | 5 - 40 | 25 |
| Total Phosphorus | 1 - 70 | 30 |
| Alkalinity | 1,000 - 10,000 | 3,000 |
| pH | 5.3 - 8.5 | 6 |
| Hardness | 300 - 10,000 | 3,500 |
| Calcium | 200 - 3,000 | 1,000 |
| Magnesium | 50 - 1,500 | 250 |
| Potassium | 200 - 2,000 | 300 |
| Sodium | 200 - 2,000 | 500 |
| Chloride | 100 - 3,000 | 500 |
| Sulfate | 100 - 1,500 | 300 |
| Iron | 50 - 600 | 60 |

In the case of polyester, it is important to determine if hydrolysis can occur. Equally important in practical terms is to determine if the leachate forms a buffered solution which will inhibit hydrolysis. That is, the acids and bases will react with each other preferentially to form salts instead of attacking the polyester.

Again, because of the variance in composition, caution should be used when describing a typical leachate. Therefore, it is best to characterize the actual leachate before designing the geotextile for a given location.

Aging and Durability Factors

Most of the effects discussed in this presentation have dealt with general properties of polyester exposed to a variety of individual conditions. Due to time limitations, it is not possible to deal with all the factors, nor combinations of factors which could effect the aging and durability of polyester geotextiles. There are, however, a number of other important factors which should be considered, discussed or studied before selecting the geotextile fabric for a given application. For example, it is very important to know the time and temperature since these play a key role in the degree and rate of reactivity. The denier (or thickness of the fiber and fabric) greatly influences the degree and rate of reaction, especially where surface attack predominates. Similarly, high molecular orientation levels (crystallinity) can slow down or prevent degradation in which the mechanism involves absorption of the degradant into the fiber.

Another factor is the molecular weight (or chain length) of the polymer which affects ultimate strength. Breakage of an ester linkage in a high molecular weight material may show a higher strength loss initially, but the retained strength over time may be much greater. Also, fiber properties such as crimp play a role in the inherent strength and retained strength, because it weakens the fiber at the crimp points. This is accentuated with sharp, edged mechanical crimp.

These factors and others should be taken into account when designing a geotextile fabric for a given application.

SUMMARY AND CONCLUSIONS

In closing, polyester's great versatility for selective engineering yields a broad range of geotextile products with excellent strength, toughness and dimensional stability. This is the case in wet or dry conditions. In addition, the weight of the fabric is affected to only a very limited extent by water absorption. Furthermore, resistance to permanent deformation (creep) under long-term loading is excellent. Also, polyester is inert to a wide range of chemical classes encountered in soil. And superior sunlight resistance allows handling of polyester geotextiles in most jobs. Finally, polyester geotextiles are not affected by microorganisms in soil.

Because of polyester's excellent chemical and physical properties, this material can be used with confidence in almost any geotextile environment where aging and durability features are desired.

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APPENDIX 12:
▪ **GEOTEXTILE INFORMATION**
DETAILS OF GEOTEXTILE

ELCOMAX[®]

Engineered Geotextiles for Coastal Applications

Engineered Geotextiles
for Coastal Applications



ELCO
SOLUTIONS PTY LTD



ELCOMAX®

THE ENGINEERED SOLUTION TO COASTAL APPLICATIONS

ELCOMAX® non-woven staple fibre Geotextiles were purpose designed in the 1960's by Naue Fasertechnik of Germany in answer to the increasing hydraulic demands placed on revetment systems. The unique characteristics of staple fibre non-woven Geotextiles allows for coastal engineers to specify mechanical and hydraulic criteria to meet the needs of the most rigorous applications.

Since the 1970's, ELCO SOLUTIONS and ELCOMAX® have been supplying engineered innovative technology to some of our regions most demanding coastal projects.

REVETMENT ARMOUR STONE

The Nerang River Training Walls project, constructed for the Gold Coast Waterways Authority and the Queensland Government by Leighton - Candac, utilised over 72,000m² of ELCOMAX® 1200R Geotextile.



NERANG RIVER TRAINING WALLS



PALM BEACH

BEACHFRONT ARMOUR ROCK PROTECTION

ELCOMAX® has played an important role in protecting some of Australia's most valuable waterfront properties. Coastal boulder wall construction utilising heavy duty ELCOMAX® Geotextiles are now standard practice.

ELCOMAX® GEOTEXTILE CONTAINERS — ELCOROCK®

Since the early 1980's, ELCO SOLUTIONS have worked consistently developing "soft solutions" for coastal engineers, utilising ELCOMAX® non-woven Geotextiles. Our range includes fabricated ELCOMAX® Geotextiles for hydraulically filled tubes and dry filled Geocontainers up to 300 tonnes in mass. Increasing environmental concerns see these products applied in sea walls, groynes, artificial reefs and emergency containment. Recent developments have seen the expanded range to include mega-sand containers up to 4.6 metre diameter for placement by bottom dumping barge or insitu filling.



STOCKTON BEACH

CONTAINMENT BAGS

ELCOROCK® Geocontainers were used to construct a sea defence to protect Stockton Beach Surf Life Saving Club from the ravages of the ocean. Over 400, 2-tonne Geocontainers laid on ELCOMAX® 1200R filter cloth, replaced the traditional rock armour design.

ELCOMAX® TUBES

ELCOMAX® sand filled tubes with a diameter of 1.0 metre ultimately saved this house from the ravages of cyclone Justin in far North Queensland. The inherent flexibility of the ELCOMAX® tubes is a distinct advantage.



RUSSELL HEADS

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Australian Manufacturers of a diverse range of specialist geosynthetics

Phone: + 61 7 5500 1400 • Fax: + 61 7 5539 4027

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ELCOMAX® *Geotextiles for Coastal Applications*



- Beachfront Armour Rock Protection • Silt Curtains • ELCOROCK® Containers and Tubes

| ELCOMAX® Marine and Heavy Grade Polyester Geotextiles – Up to 3000g/m ² for heavy duty performance | | | | | | | |
|---|-----------|------------------------|-------------|----------|-----------------------------|-----------|-----------------------|
| Grade | Thickness | Drop Cone | CBR Burst | G Rating | Wide Strip Tensile Strength | Pore Size | Flow Rate |
| 600R | 4.8mm | H ₅₀ 6 000 | 4 700N @70% | 5 300 | 33kN/m XD 18kN/m MD | <75µm | 80L/m ² /s |
| 900R | 5.4mm | H ₅₀ 10 300 | 7 400N @70% | 8 700 | 50kN/m XD 28kN/m MD | <75µm | 60L/m ² /s |
| 1200R | 5.7mm | H ₅₀ 12 600 | 9 600N @70% | 10 900 | 68kN/m XD 38kN/m MD | <75µm | 27Lm ² /s |



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