REPORT

香港機場管理局 AIRPORT AUTHORITY HONG KONG

LEIGHTON 禮頓

Leighton Contractors (Asia) Limited

Permanent Aviation Fuel Facility

Bubble Jacket Trial

Summary Report

31st January 2005

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REPORT

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Permanent Aviation Fuel Facility:

Bubble Jacket Trial
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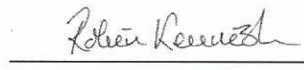
For and on behalf of Environmental Resources Management	
Approved by:	Dr Robin Kennish
Signed:	
Position:	Technical Director
Date:	31st January 2005

CONTENTS

1 INTRODUCTION

As part of the Permanent Aviation Fuel Facility (PAFF) a two berth jetty will be constructed. This jetty will be sited approximately 200m offshore at Tuen Mun Area 38. The main activity at the jetty will be berthing/unberthing of tankers and the pumping of aviation fuel to the tanks in the tank farm. A total of 106 piles will be required for the construction of the jetty where water is approximately 17m deep. The percussive piling is expected to take about 6 weeks.

The potential environmental impacts of the Project have been studied in the Environmental Impact Assessment (EIA) Report *"Permanent Aviation Fuel Facility for Hong Kong International Airport"* (*EIAO Register No: AEIAR-062/2002*). The EIA was approved with conditions on 2 August 2002 under the *Environmental Impact Assessment Ordinance (EIAO)*. An Environmental Permit (EP) (*EP-139/2002*) associated with the construction works was granted on 28 August 2002 and a Variation to the Environmental Permit was granted on 24 February 2004 (*EP-139/2002/A*).

To reduce the potential impact on the local population of Indo-Pacific Humpback Dolphin (*Sousa chinensis*), a condition of the EP is that a bubble jacket is employed during piling works associated with the construction of the proposed jetty. However, prior to the actual pile construction, the effect on noise attenuation of the proposed bubble jacket was tested to determine whether the performance of the proposed bubble jacket type provides the same, if not better, noise attenuation compared to that provided by the bubble curtain employed during the construction of the AFRF at Sha Chau.

This *Summary Report (SR)* presents the findings of the bubble jacket trial in terms of the effectiveness of the two proposed bubble jacket types in reducing underwater noise during percussive piling and their ability to meet the conditions of the EP.

2 OBJECTIVES AND METHODOLOGY

2.1 OBJECTIVES

2.1.1 Noise Mitigation

The objective of the bubble jacket is to reduce the potential impact on the local dolphin population based on the conditions of the EP, as follows

Condition 3.2:

> *"Trial of bubble jacket shall be carried out to demonstrate noise attenuation effect of 3 dB or more as recommended in the approved EIA Report (Register No. AEIAR-062/2002)."*

And, *Condition 3.24*:

> *"Bubble jacket shall be used for piling work to reduce underwater piling noise to achieve the following underwater mitigated noise levels:*

Distance from Piling Work (m)	*Noise Level (dB)*
250	*162*
500	*152*
1000	*145*

2.1.2 Sound and Sound Measurement

Sound and its measurement are technical subjects. Some key terms and concepts are described below in order to help give an understanding of how the results are reported and what they mean.

Sound originates as a wave motion by a vibrating source and requires for its transmission an elastic medium such as air, water or a solid.

The frequency (f) or the pitch of the sound is the number of cycles, or pressure fluctuations, produced per second. Frequency is expressed in units of Hertz (Hz) or cycles per second. The wavelength (λ) is the distance between successive waveform repetitions. A low frequency sound has a long wavelength, whereas a high frequency sound has a short wavelength (higher frequencies result in high-pitched sounds). Sounds in this trial were recorded from 100 Hz to about 25.6 Kilohertz (kHz) (the Broadband range), approximately throughout the human hearing range and a little above it.

Use of a logarithmic decibel (dB) scale compresses the vast range of numbers required to describe the wide range of sound pressures. The sound pressure level, in general, is the decibel level of a sound relative to the ambient sound pressure in Pascals. The decibel is a relative, not an absolute, unit and to be meaningful must have a reference value.

In air, sound sources are conventionally described either in terms of the sound pressure level referenced to 20 microPascals (ie 20 x 10^{-6} Pa) at a specified distance (usually 1m). Whereas in water, sound sources are described in terms of the sound pressure level reference to 1 microPascal (ie 1 x 10^{-6} Pa) at a specified distance (usually 1m).

In this trial the median underwater sound pressure density spectrum values were integrated into one-octave band frequency widths of 100 Hz to 25.6 kHz. For each mitigation method, the attenuation was calculated as the ratio of mitigated noise for each octave divided by the corresponding octave for unmitigated noise at that position.

2.1.3 *Dolphin Sensitive hearing Range*

In order to ensure that the mitigation measures are focussed on minimising impacts to dolphins, the results of the bubble jacket trial have been analysed in terms of both the Broadband Range and the EIA-identified Dolphin Sensitive Range.

The **Broadband Range** has been taken as 100 Hz to 25.6 kHz, which is the range measured in the bubble curtain study during the construction of the AFRF [1]. As much of the rationale behind the current bubble jacket trial has been based on the assessment of this work in the EIA, and subsequently taken forward to the EP, this range is considered appropriate to ensure that the results of the two studies are directly comparable.

The **EIA Dolphin Sensitive Range** has been taken as 400 Hz to 12.6 kHz. Although a precise audiogram for the Indo-Pacific Humpback Dolphin (*Sousa chinensis*) does not exist, bottlenose dolphins (*Tursiops truncatus*) have comparable internal ear morphology [2] and have been shown to be sensitive in the single-digit kHz frequencies (1 kHz to 10 kHz) where they conduct the majority of their low frequency whistling [3]. However, according to the EIA for the PAFF, dolphins, in general have acute hearing above 500 Hz and have been found to communicate within the 400 to 800 Hz range [4]. Lower frequency sounds are sounds to which the dolphins are probably not as sensitive and in which frequency range they appear to communicate very little [5]. It has, therefore, been considered that as a precautionary approach noise measurements should also be analysed within a Dolphin Sensitive Range of 400 Hz to 12.6 kHz. Analysis within this range will allow a greater

(1) B Wursig, C.R. Greene, T. A Jefferson (1999) Development of an air bubble curtain to reduce underwater noise of percussive piling. Marine Environmental Research.

(2) Ketten, D. R. (1991). The marine mammal ear: specializations for aquatic audition and echolocation. In D. Webster, R. Fay, & A. Popper, The biology of hearing (pp. 717-750). Berlin: Springer Verlag.92B.

(3) Herman, L. M., & Arbeit, W. R. (1972). Frequency difference limens in the bottlenose dolphin: 1-70 cs/s. J. Aud. Res., 12, 109-120

(4) Mouchel Asia Limited (2002) Environmental Impact Assessment for a Permanent Aviation Fuel Facility for Hong Kong International Airport. Final Report for the Airport Authority Hong Kong.

(5) B Wursig, Personal Communication, 1996

indication of the potential for impacts to dolphins through percussive piling works.

2.1.4 *Dolphin Monitoring*

As a precautionary measure, to meet the construction phase requirements of the EP, a 500 m dolphin exclusion zone was implemented throughout the duration of the bubble jacket trial. The objective of the exclusion zone was to ensure that the works area was continuously clear of dolphins before and during the bubble jacket trial to further reduce the potential adverse impacts to dolphins.

2.2 METHODOLOGY

2.2.1 *Percussive Piling*

As approved in the EIA (*EIAO Register No: AEIAR-062/2002*), percussive piling will be used for the construction of the jetty. The method used in the bubble jacket trial and proposed for use in the construction of the PAFF is largely the same as that used previously in the construction of the AFRF at Sha Chau.

The general design of the percussive piling technique involves the use of a hammer and anvil system that is lowered onto the top of the pile by steel wires from the construction barge's derrick (1). The hammer slides up and down inside the frame, driving the pile into the seabed. The anvil between the pile and hammer is used to ensure that the force of the blow is distributed evenly.

2.2.2 *Bubble Jacket Types*

To achieve the mitigated noise levels, two general designs of bubble jacket types were tested with a total of seven variations of the general designs to determine which arrangements met the conditions of the EP, as shown in *Table 2.1* (2). All options used air bubbles to reduce noise by reflecting, scattering and absorbing the noise (in the form of underwater pressure pulses) produced by the piling works.

The general designs were the Canadian Bubble Jacket or the Fixed Steel Bubble Jacket. The Canadian Bubble Jacket consists of steel rings placed around the pile at the selected depths, from which bubbles are released rising to the surface up and around the pile (*Figure 2.1*). In contrast, with the Fixed Steel Bubble Jacket design, air bubbles are released close to the seabed inside a steel jacket fitted with neoprene spacers to prevent the jacket contacting the

(1) It should be noted that a heavier hammer was used in the bubble jacket trial compared to that used in the AFRF study due to higher capacity piles being required for the PAFF as a result of deeper water and the larger vessel berth capacity.

(2) Although a bubble curtain following the same design as that used in the AFRF study was also tested, this design was unsuccessful. A combination of high water current velocities and deep water resulted in the wide diameter frame buckling during deployment.

pile. The bubbles displace water upwards creating an air pocket around the pile that reduces noise being transmitted to the water outside the steel jacket (*Figure 2.2*).

One of the variants of the general designs described above incorporated an air bubble curtain at 1m below the sea surface immediately around the piling barge in an attempt to further attenuate noise levels. In another, the air pressure supplied to the air lines was varied in order to determine the air pressure resulting in the most noise attenuation.

In addition, a bubble curtain similar to that used during the construction of the AFRF at Sha Chau was tested. Unfortunately, due to a combination of high water current velocities and deep water resulting in the need for a wide diameter air ring, the frame for the bubble curtain buckled during deployment and was thus unsuccessful. It would appear that if such equipment were unable to be deployed during the trial at the proposed construction site, it would not be suitable to be deployed as a mitigation method during actual construction works. No noise measurements were taken using this method and it is, therefore, not discussed further.

2.3 *NOISE MEASUREMENT*

2.3.1 *Noise Measurement Positions*

In order to verify whether the proposed bubble jacket options meet the criteria specified in the EP, noise measurements were taken at a total of five positions, at several distances from the piling barge during the piling works (*Figure 2.3*). Sound measurements were taken at positions 1 and 2 as well as position 3 (all 250m from the piling barge) in order to attempt to determine whether direction from the piling barge had any influence on underwater noise measurements.

Positions 3, 4 and 5 were chosen in accordance with the distances specified in the EP, ie at 250m, 500m and 1km away from the test pile. These positions extended out into the Urmston Road Channel in the direction of the Sha Chau and Lung Kwu Chau Marine Park.

2.3.2 *Ambient Noise Measurement*

Ambient noise levels were measured every day at each position. Before noise measurements were made, all sources of noise on the survey boat were turned off except for a quiet generator used to run navigation equipment and recording computers. The generator was placed on soft rubber mounts on the upper deck to ensure minimal noise from this source. In order to collect ambient measurements, the survey vessel was allowed to drift in positions 1, 2, 5 and 4, it was then anchored in position 3 in preparation for measurements during piling operations. All measurements were taken at mid depth.

2.3.3 *Noise Measurements Recorded during Percussive Piling*

In contrast to the ambient noise measurements, in order to collect noise measurements during percussive piling activities, the survey vessel was anchored at each position to allow recordings of noise levels from a consecutive set of hammer blows to be made at the same point.

The first set of noise measurements were taken without any mitigation measures in place after a signal from the survey vessel indicated that piling works should start. Each measurement was then checked to make sure it was suitable. Some measurements were discarded and re-recorded due to the recording being clipped, a passing ship generating noise or inconsistencies in the hammering due to vessel wash rocking the piling barge. After an acceptable measurement had been taken, the mitigation methods and their variations were tested in each position. The last measurement taken was another measurement of ambient noise. All measurements were taken at mid depth [1].

2.4 *DOLPHIN MONITORING*

A dolphin exclusion zone within a radius of 500m from the piling barge was implemented during piling activities for the bubble jacket trial. Piling was not allowed to commence until the experienced and approved dolphin monitor from the Environmental Team had certified that the area was continuously clear of dolphins for a period of 30 minutes (thereby adequately spanning the approximate maximum dive time of the dolphins of 4 minutes). If dolphins were found to have moved into the exclusion zone, piling operations would cease and not resume until the dolphin monitor confirmed that the zone had been continuously clear of dolphins for a period of 30 minutes.

Dolphin monitoring was conducted according to locally accepted monitoring techniques as specified in the EIA. In addition to sightings of dolphins, records of weather conditions, Beaufort Scale and visibility were recorded to assist interpretation of results.

The results of the dolphin monitoring conducted during the bubble jacket trial are presented in *Table 2.2*.

No dolphins were recorded within the dolphin exclusion zone during the three-day bubble jacket trial. It is also worth noting that no sightings of dolphins were made within the waters outside of the dolphin exclusion zone.

(1) EGS (Asia) Limited (2004) Permanent Aviation Fuel Facility Planned Jetty at Area 38. Tests of Noise Mitigation Methods to be used during Percussion Piling. Sound Attenuation Measurements Final Report. For Leighton Contractors (Asia) Ltd.

3 RESULTS

3.1 SURVEY

Underwater noise measurements were recorded on the 23rd to 25th March 2004. All noise measurements reported in this SR were collected by EGS (Asia) Limited. The Airport Authority Hong Kong (AAHK), Leighton Contractors (Asia) and the Environmental Team (ERM-Hong Kong Limited) provided on-site survey supervision. The Environmental Team also provided precautionary dolphin monitoring. In addition, the Environmental Protection Department (EPD), Agriculture, Fisheries and Conservation Department (AFCD) and the Civil Engineering and Development Department (CEDD) of the Hong Kong SAR Government were invited to attend any or all of the trials with representatives attending one or more of the survey days.

3.2 NOISE MEASUREMENTS

3.2.1 *Broadband Noise Levels and Noise Attenuation*

The results of the noise measurements for all of the options in terms of individual frequencies are presented in the *Annex*. The results in terms of noise within the Broadband Range (100 Hz to 25.6 kHz) and within the EIA Dolphin Sensitive Range (400 Hz to 12.6 kHz) are presented in *Tables 3.1* and *3.2*, respectively.

When compared to the requirements of the EP within the Broadband Range no option appeared to meet the requirements at all distances. However, in comparison to the EIA Dolphin Sensitive Range, it would appear that Option 7 mitigates noise sufficiently to meet the requirements at all distances. Although noise attenuation of -3 dB or more was not achieved at Position 2 (250 m), the unmitigated noise level at this position was already below the noise criteria of 162 dB (Mitigated Noise Level at Position 2 for Option 7 = 158.0 dB). Results from the three 250 m locations show that although there are variations with direction, these are small compared with attenuation levels achieved with the mitigation techniques. As three sets of measurements were taken at this distance, average measurements from all three have been used in determining the 250 m attenuated noise level. The average attenuation at 250m was 4.5 dB, which also satisfies the EP requirements. The ability of Option 7 to meet the EP requirements in the EIA Dolphin Sensitive Range is presented in *Figure 3.1*.

The results in *Tables 3.1* and *3.2* indicated additional attenuation of sound through the employment of the bubble curtain around the barge was inconsistent. Additional attenuation was, however, occasionally achieved.

4 DISCUSSION

The results of the bubble jacket trial show that, when comparing results for the EIA Dolphin Sensitive Range (400 Hz to 12.6 kHz), Option 7, a combination of the Fixed Steel Bubble Jacket combined with a lower ring of the Canadian Bubble Jacket, successfully met the noise criteria specified in the EP. As the primary objective of the bubble jacket is to mitigate against adverse noise impacts to the local population of the Indo-Pacific Humpback Dolphin (*Sousa chinensis*), it is considered more appropriate to identify the appropriate mitigation measure within this range than the Broadband Range (100 Hz to 25.6 kHz).

It is also important to compare circumstances and results to those from the percussive piling operations for the Aviation Fuel Receiving Facility (AFRF) at Sha Chau [1]. The noise levels recorded in the AFRF study were seen to be lower than those in the present study. This was due to factors such as a smaller hammer being used, smaller and shorter piles, and the shallower water depth. The greater absorption and multiple scattering from the sea bed/sea surface in the Sha Chau area provided a level of natural attenuation in the AFRF study, which was limited in the current study.

It is also noted from the results that whilst not consistently successful in further attenuating noise, the employment of the bubble curtain around the barge provided generally positive mitigation results. Again although not conclusive, reduced and increased air pressure tests also indicated that varying the air pressure to the air hose affected the efficacy of the mitigation.

(1) B Wursig, C.R. Greene, T. A Jefferson (1999) *Op cit.*

5 *RECOMMENDATIONS*

This report has presented the results of a bubble jacket trial conducted in March 2004 at the proposed construction site. Based on the findings of the trial, it is recommended that Option 7, a combination of the Fixed Steel Bubble Jacket and the lower ring of the Canadian Bubble Jacket, be taken forward as the proposed mitigation method to be employed during construction of the PAFF jetty. Deployment of this option during percussive piling activities would mitigate against adverse underwater pressure pulses such that *EP-139/2002/A Conditions 3.2* and *3.24* are met.

In order to provide maximum effectiveness of sound attenuation, it is also recommended that the bubble curtain around the hull of the barge be combined with Option 7 during construction. Furthermore, to further improve the overall mitigation, it is recommended that variations of air pressure should be tested during construction noise measurements.

No changes are recommended to the existing dolphin monitoring programme and the present requirement of a 500 m dolphin exclusion zone to be created during all piling activities is supported.

Tables and Figures

Table 2.1 ***Variations in the Bubble Jacket System***

Options	Bubble Jacket System
1	Canadian Bubble Jacket with 3 Rings
2	Canadian Bubble Jacket with 3 Rings plus bubble curtain around barge
3	Canadian Bubble Jacket with 4 Rings
4	Canadian Bubble Jacket with 4 Rings plus bubble curtain around barge
5	Fixed Steel Bubble Jacket
6	Fixed Steel Bubble Jacket plus bubble curtain around barge
7	Fixed Steel Bubble Jacket plus lowest ring of bubble jacket

Table 2.2 ***Results of the Dolphin Monitoring during the Bubble Jacket Trial***

	Date		
	23rd March 2004	**24th March 2004**	**25th March 2004**
Weather	Cloudy	Cloudy with occasional rain patches	Cloudy with occasional rain patches
Visibility	Unlimited	Unlimited	< 2 km
Beaufort Scale	3 - 4	3 - 4	3 - 5
Dolphin Sightings	Nil	Nil	Nil

Table 3.1 Broadband Noise Levels and Noise Attenuation within the Broadband Range 100 Hz to 25.6 kHz

Position	EP Criteria (dB)	Ambient Levels (dB)	Unmitigated Noise Levels (dB)	Mitigated Noise Levels (dB)							Attenuation in Noise Levels (dB)						
				Option							Option						
				1	2	3	4	5	6	7	1	2	3	4	5	6	7
1 (250m)	162	135.2	167.3	162.6	162.1	165.8	164.9	161.8	162.0	161.7	4.7	5.2	1.5	2.4	5.5	5.3	5.6
2 (250m)	162	133.6	163.2	161.8	161.8	162.3	163.0	162.2	161.8	161.5	1.4	1.4	0.9	0.1	1.0	1.4	1.7
3 (250m)	162	134.8	168.4	168.1	168.2	165.8	165.9	163.2	163.1	163.4	0.3	0.1	2.6	2.5	5.2	5.3	5.0
4 (500m)	152	132.8	162.1	159.7	160.2	160.0	160.4	158.8	156.4	156.8	2.4	1.9	2.1	1.7	3.3	5.6	5.2
5 (1,000m)	145	133.7	157.5	153.5	151.2	154.1	153.7	150.7	151.2	150.6	4.0	6.4	3.4	3.8	6.8	6.3	7.0

Note: Shaded Cells indicates Mitigation Measure meets EP Requirements

Table 3.2 Broadband Noise Levels and Noise Attenuation within the EIA Dolphin Sensitive Range 400 Hz to 12.8 kHz)

Position	EP Criteria (dB)	Ambient Levels (dB)	Unmitigated Noise Levels (dB)	Mitigated Noise Levels (dB)							Attenuation in Noise Levels (dB)						
				Option							Option						
				1	2	3	4	5	6	7	1	2	3	4	5	6	7
1 (250m)	162	133.1	163.9	158.8	158.6	161.7	159.7	158.3	157.9	157.8	5.2	5.3	2.2	4.3	5.6	6.1	6.1
2 (250m)	162	132.0	159.7	158.9	157.9	156.5	156.8	159.4	159.3	158.0	0.8	1.8	3.2	2.9	0.3	0.4	1.7
3 (250m)	162	133.0	165.1	164.2	165.1	163.8	162.8	159.3	159.3	159.3	0.9	-0.1	1.3	2.3	5.7	5.7	5.7
4 (500m)	152	131.8	156.2	155.8	157.0	154.4	154.3	153.2	151.7	152.0	0.4	-0.9	1.8	1.8	3.0	4.5	4.2
5 (1,000m)	145	131.8	152.5	149.0	145.5	146.1	145.4	143.8	147.0	143.5	3.5	7.0	6.3	7.1	8.7	5.4	9.0

Note: Shaded Cells indicates Mitigation Measure meets EP Requirements

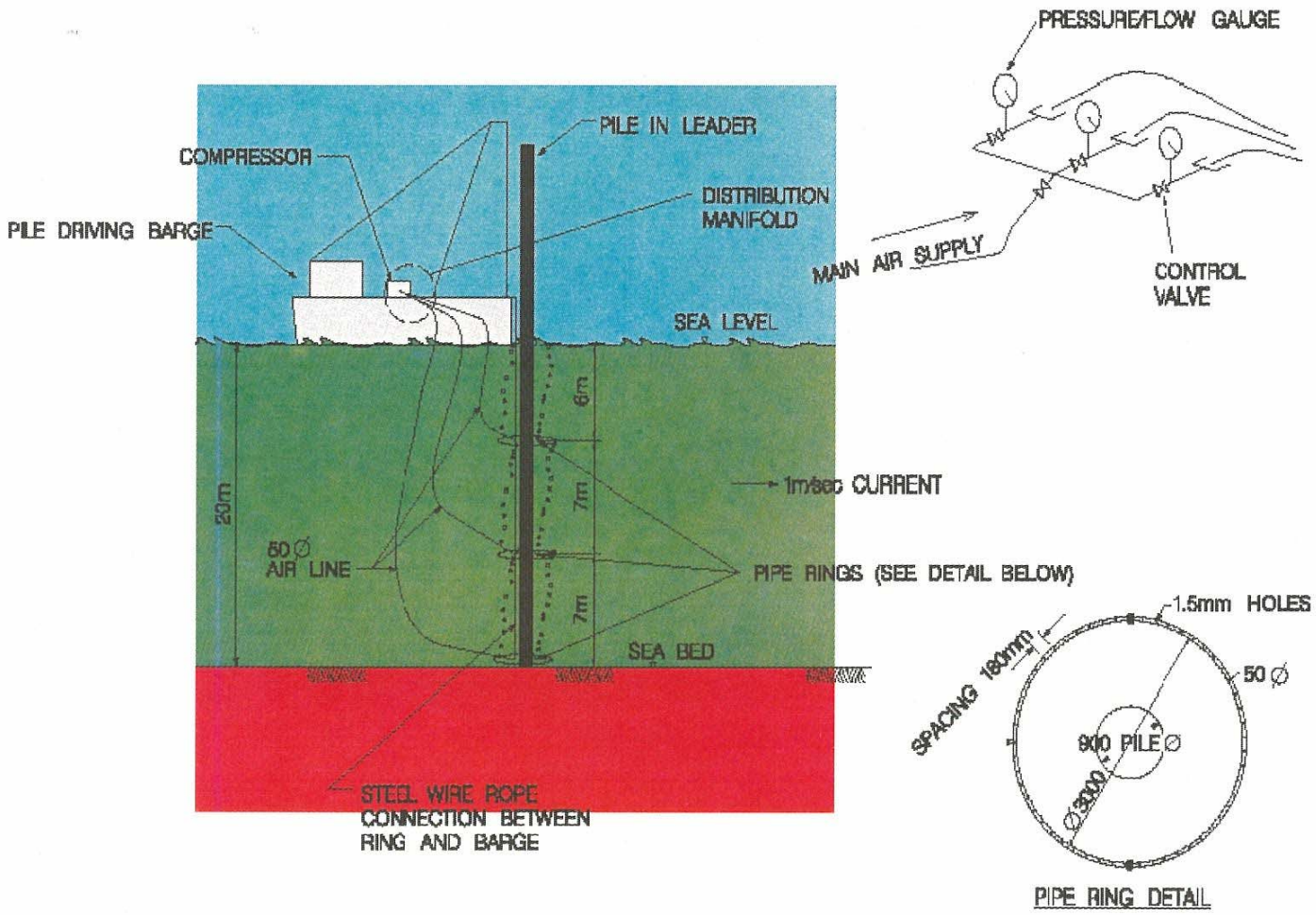


Figure 2.1 Schematic of a Canadian Bubble Jacket (Options 1 to 4)

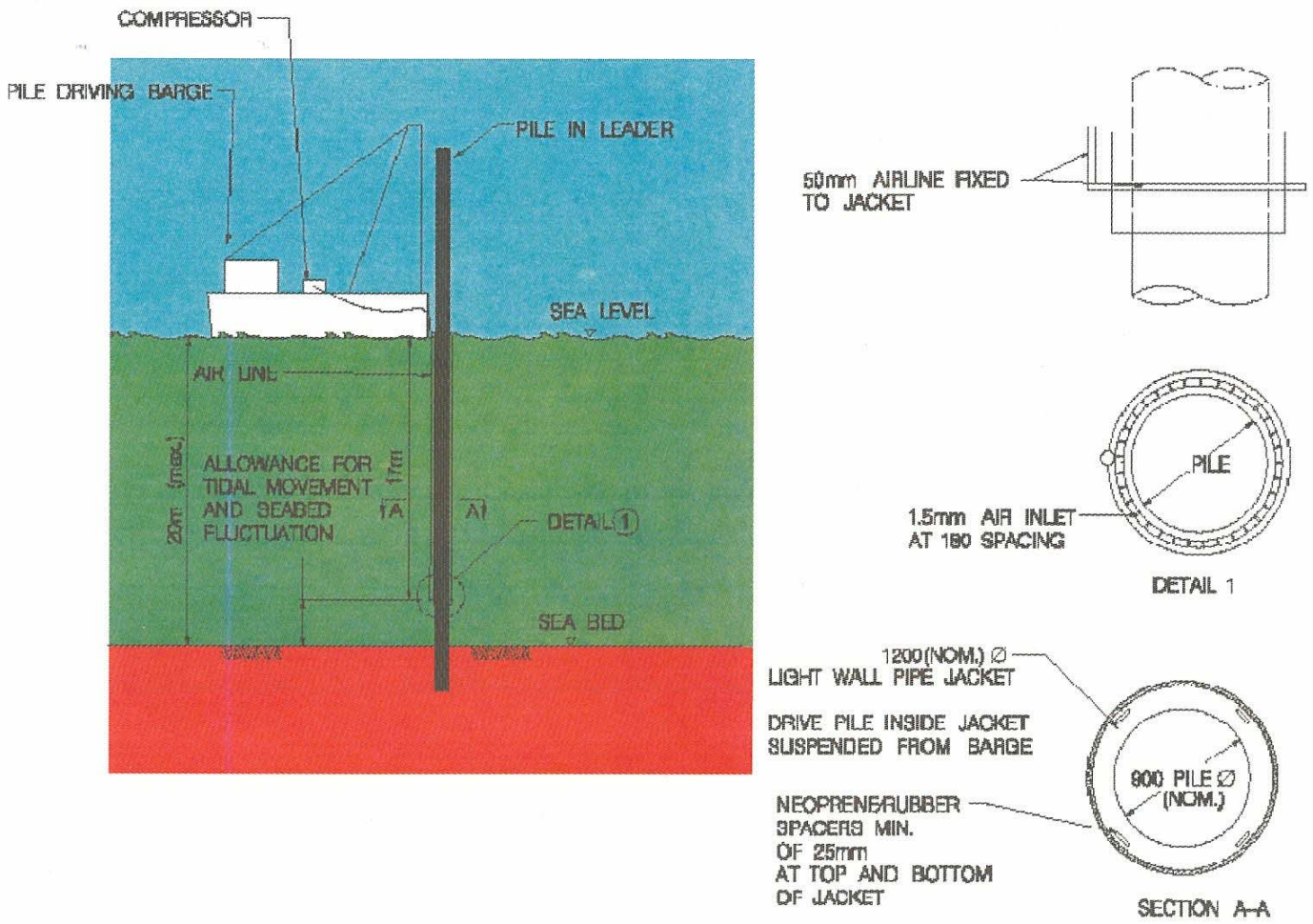


Figure 2.2 Schematic of a Fixed Bubble Jacket (Options 5 to 7)

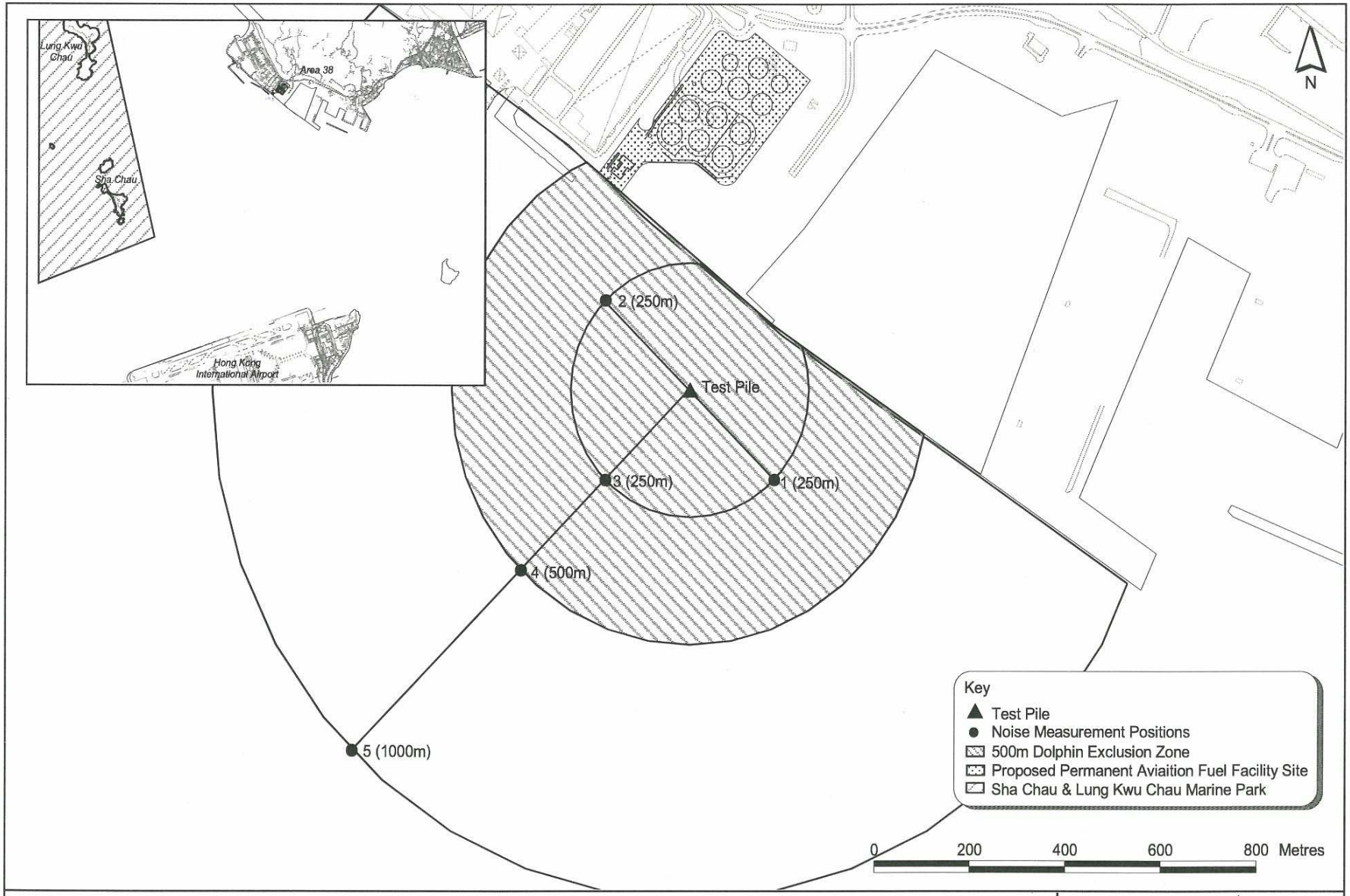


FIGURE 2.3

Location of Noise Measurement Positions

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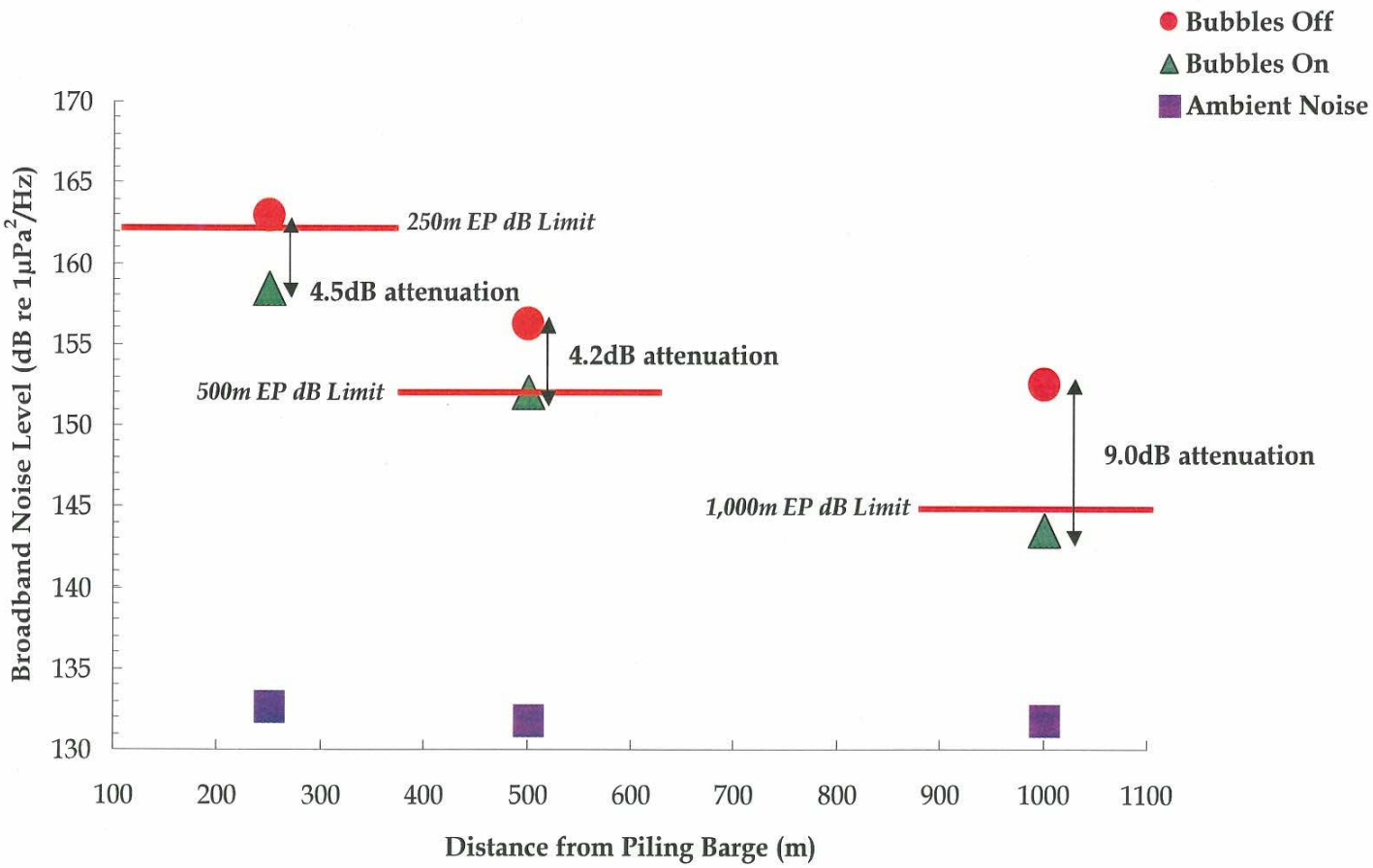

Figure 3.1 Broadband Noise Mitigation (EIA Dolphin Sensitive Range 400 Hz to 12.8 kHz) Achieved by Option 7 at all Distances from the Test Pile

Annex

Noise Attenuation Results

Table 1 - Variations in the Bubble Jacket System

Options	Bubble Jacket System
1	Canadian Bubble Jacket with 3 Rings
2	Canadian Bubble Jacket with 3 Rings plus bubble curtain around barge
3	Canadian Bubble Jacket with 4 Rings
4	Canadian Bubble Jacket with 4 Rings plus bubble curtain around barge
5	Fixed Type Bubble Jacket
6	Fixed Type Bubble Jacket plus bubble curtain around barge
7	Fixed Type Bubble Jacket plus lowest ring of bubble jacket

Sound Pressure Levels (dB re 1µPa)

POSITION 1 - Distance to Barge 250m

Frequency (Hz)	Ambient	Unmitigated	Mitigation Method (see Table 2.1 of Main Report for description of reference numbers)						
			Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
100	126.8	157.9	155.8	154.8	156.9	157.4	155.6	155.5	156.0
200	128.9	163.6	158.5	157.8	162.7	162.1	156.8	157.9	156.8
400	132.0	163.0	158.0	157.7	161.0	159.1	157.2	156.4	156.6
800	124.9	155.5	150.2	150.8	152.7	149.6	150.5	151.5	151.1
1,600	117.3	148.9	141.9	142.5	143.4	142.7	144.9	143.7	143.4
3,200	116.0	144.5	130.5	129.7	136.4	133.4	132.2	133.6	133.6
6,400	113.0	142.2	127.1	128.0	134.0	131.9	129.7	129.4	130.3
12,800	110.1	139.3	124.7	124.9	133.0	131.0	129.4	129.1	130.6
25,600	108.8	138.1	122.9	123.9	132.5	131.1	129.1	129.0	129.7
Broadband Range (100 Hz to 25.6k Hz)	**135.2**	**167.3**	**162.6**	**162.1**	**165.8**	**164.9**	**161.8**	**162.0**	**161.7**
Dolphin Sensitive Range (400 Hz to 12.8k Hz)	**133.1**	**163.9**	**158.8**	**158.6**	**161.7**	**159.7**	**158.3**	**157.9**	**157.8**

POSITION 2 - Distance to Barge 250m

Frequency (Hz)	Ambient	Unmitigated	Mitigation Method (see Table 2.1 of Main Report for description of reference numbers)						
			Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
100	124.8	157.0	155.6	156.6	158.5	158.3	153.0	152.6	153.5
200	126.1	158.1	155.6	156.3	157.5	159.4	157.5	157.0	157.4
400	131.1	158.9	157.8	157.1	156.1	156.3	159.1	159.1	157.5
800	123.9	149.4	150.8	149.1	143.9	145.9	146.6	144.5	147.3
1,600	113.1	145.1	145.4	143.2	138.5	140.0	140.7	139.7	139.5
3,200	110.8	143.4	140.0	137.3	134.4	134.4	134.1	134.4	132.7
6,400	110.4	140.6	137.8	133.8	131.7	131.6	130.6	129.5	129.5
12,800	107.4	139.4	137.0	133.1	132.1	131.3	130.0	127.9	127.9
25,600	106.8	139.0	134.6	131.2	132.2	131.3	128.8	126.9	126.6
Broadband Range (100 Hz to 25.6k Hz)	**133.6**	**163.2**	**161.8**	**161.8**	**162.3**	**163.0**	**162.2**	**161.8**	**161.5**
Dolphin Sensitive Range (400 Hz to 12.8k Hz)	**132.0**	**159.7**	**158.9**	**157.9**	**156.5**	**156.8**	**159.4**	**159.3**	**158.0**

Sound Pressure Levels (dB re 1µPa)

POSITION 3 - Distance to Barge 250m

Frequency (Hz)	Ambient	Unmitigated	Mitigation Method (see Table 2.1 of Main Report for description of reference numbers)						
			Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
100	128.0	160.9	162.5	161.3	155.7	157.3	157.3	156.5	156.6
200	126.2	163.9	163.1	163.2	160.3	161.6	158.3	158.8	159.3
400	132.0	163.8	163.2	164.5	163.1	162.4	157.8	157.9	158.3
800	124.8	157.7	155.8	155.9	154.6	151.1	153.4	153.0	151.7
1,600	116.7	150.9	150.2	146.6	145.7	144.8	144.4	144.8	144.7
3,200	114.1	145.9	144.3	139.9	136.8	134.1	132.1	133.9	132.4
6,400	114.7	143.5	142.5	137.9	133.9	131.3	129.2	129.0	129.1
12,800	109.6	141.9	140.8	135.0	133.5	130.7	127.9	127.4	126.5
25,600	109.9	141.3	139.2	133.5	134.4	132.0	128.5	127.7	127.1
Broadband Range (100 Hz to 25.6k Hz)	**134.8**	**168.4**	**168.1**	**168.2**	**165.8**	**165.9**	**163.2**	**163.1**	**163.4**
Dolphin Sensitive Range (400 Hz to 12.8k Hz)	**133.0**	**165.1**	**164.2**	**165.1**	**163.8**	**162.8**	**159.3**	**159.3**	**159.3**

POSITION 4 - Distance to Barge 500m

Frequency (Hz)	Ambient	Unmitigated	Mitigation Method (see Table 2.1 of Main Report for description of reference numbers)						
			Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
100	119.8	153.8	151.8	151.9	154.0	154.3	151.5	149.4	149.7
200	124.9	159.8	155.9	155.9	156.7	157.5	156.1	153.2	153.6
400	131.0	155.3	155.3	156.6	153.7	153.8	152.8	151.2	151.5
800	122.9	147.3	145.0	145.9	145.2	144.3	142.2	141.5	142.2
1,600	112.1	140.7	137.9	138.5	136.7	136.0	131.0	130.5	129.9
3,200	111.4	136.8	132.3	132.6	130.5	129.8	121.0	120.6	122.6
6,400	112.3	134.8	131.3	129.3	127.6	127.2	122.2	118.6	119.0
12,800	109.7	132.8	129.7	125.4	127.3	126.1	121.1	117.7	118.7
25,600	108.6	132.3	128.0	122.8	127.9	126.5	120.1	116.4	118.1
Broadband Range (100 Hz to 25.6k Hz)	**132.8**	**162.1**	**159.7**	**160.2**	**160.0**	**160.4**	**158.8**	**156.4**	**156.8**
Dolphin Sensitive Range (400 Hz to 12.8k Hz)	**131.8**	**156.2**	**155.8**	**157.0**	**154.4**	**154.3**	**153.2**	**151.7**	**152.0**

Sound Pressure Levels (dB re 1µPa)

POSITION 5 - Distance to Barge 1000m

Frequency (Hz)	Ambient	Unmitigated	Mitigation Method (see Table 2.1 of Main Report for description of reference numbers)						
			Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7
100	123.4	147.7	145.1	145.1	146.8	146.8	145.8	145.1	145.5
200	127.8	155.2	150.5	147.9	152.2	151.9	147.5	147.0	147.5
400	131.0	152.0	148.2	144.4	145.4	144.8	142.6	145.3	141.8
800	122.8	141.2	139.3	137.4	137.4	135.8	136.9	142.0	137.9
1,600	114.0	133.6	133.4	129.0	128.4	127.1	126.4	126.6	127.8
3,200	110.8	130.5	129.2	126.2	122.9	121.1	121.0	117.9	121.7
6,400	111.5	128.4	130.7	130.6	122.0	122.0	120.6	116.5	117.1
12,800	107.6	125.6	127.5	125.6	119.4	120.7	117.8	115.6	116.1
25,600	106.2	124.1	121.7	118.3	117.8	118.9	115.3	114.2	114.5
Broadband Range (100 Hz to 25.6k Hz)	**133.7**	**157.5**	**153.5**	**151.2**	**154.1**	**153.7**	**150.7**	**151.2**	**150.6**
Dolphin Sensitive Range (400 Hz to 12.8k Hz)	**131.8**	**152.5**	**149.0**	**145.5**	**146.1**	**145.4**	**143.8**	**147.0**	**143.5**