Hawaii National Marine Renewable Energy Center (HINMREC)

U.S. Department of Energy Award Number: DE-FG36-08GO18180

Task 5: Wave Energy Conversion Device Performance

WETS Deepwater Mooring Inspection

Prepared by:
Sea Engineering, Inc.

Prepared for:
Hawaii Natural Energy Institute, University of Hawaii

March 2017

HNEI
Hawai'i Natural Energy Institute
University of Hawai'i at Mānoa

Task 7E: WETS Deepwater Mooring Inspection

March 2017

Prepared for:
Luis Vega
National Marine Renewable Energy Center
Hawaii Natural Energy Institute, University of Hawaii
1680 East West Road, Post 112A
Honolulu, HI 96822

Prepared by:
Sea Engineering, Inc.
Makai Research Pier
Waimanalo, HI 96795

Job No. 25419

This page intentionally left blank

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Sea Engineering Inc. has been contracted to inspect the mooring components and WEC devices installed at the thirty meter and the two deep water berths. The inspections and documentation will be used to monitor the wear associated with the operation of a WEC device. Diver inspections are part of Task 6. This report documents results of Task 7E, the ROV inspections of the deep-water moorings. Previous inspection dates and comments are shown in Table 1-1.

Table 1-1 Task 7 Inspection Dates

Task Number	Date conducted	Comment
7A	11/13/2014; 1/21/2015	Conducted visual survey on 11/13/2014. Conducted anchor location with USBL on 1/21/2015.
7B	2/4/2016	Emergency inspection of the B2 mooring leg with broken kenter link.
7C	3/5/2016	Inspection to confirm the integrity of the A moorings for the Lifesaver install.
7D	1/11/2017	Inspection of all deep-water mooring equipment with a focus on B1 mooring leg which had broken.
7E	3/7/2017	Inspection of all deep-water moorings with a focus on broken end of B1 mooring leg and chain basket components at the 60m site.
7F		
7G		
7H		
7I		

The inspection tasks are listed below:

- ROV inspection of each of the mooring legs from the surface floats to the anchors;
- ROV inspection of PTO chain boxes at 60m site.

This report is for Task 7E conducted on March 7, 2017.

2. METHODOLOGY

2.1 Mooring Inspection

Sea Engineering Inc.'s captain and crew mobilized from of Heeia Kea Boat Harbor. The Huki Pono was utilized to deploy the Seamor Chinook ROV to survey the 60m and 80m moorings at WETS. The initial inspection of each mooring leg was completed beginning from the surface float down to the seafloor dip section of chain and to the sinker weights and anchor at the chain. For the B moorings, the dip section is the section of chain that piles up on itself from the motion of the surface float. The dip section of chain for the A moorings is the section of chain that is in intermittent contact with the seafloor or the sinker weights.

The PTO chain baskets and were inspected prior to their scheduled removal from the 60m site in April.

Figure 2-1 shows the positions of the mooring anchors, sinker weights and the surface floats for mooring legs A1, A2, and A3 at the 60m site. Dark blue contours mark five-meter depth increments and light blue contours denote one meter depth intervals. The center of the 60m site is at a depth of 58 meters. The Lifesaver WEC was present at the 60m site when the inspection was conducted. The sinker weights on the mooring chain legs are numbered alongside each mooring leg.

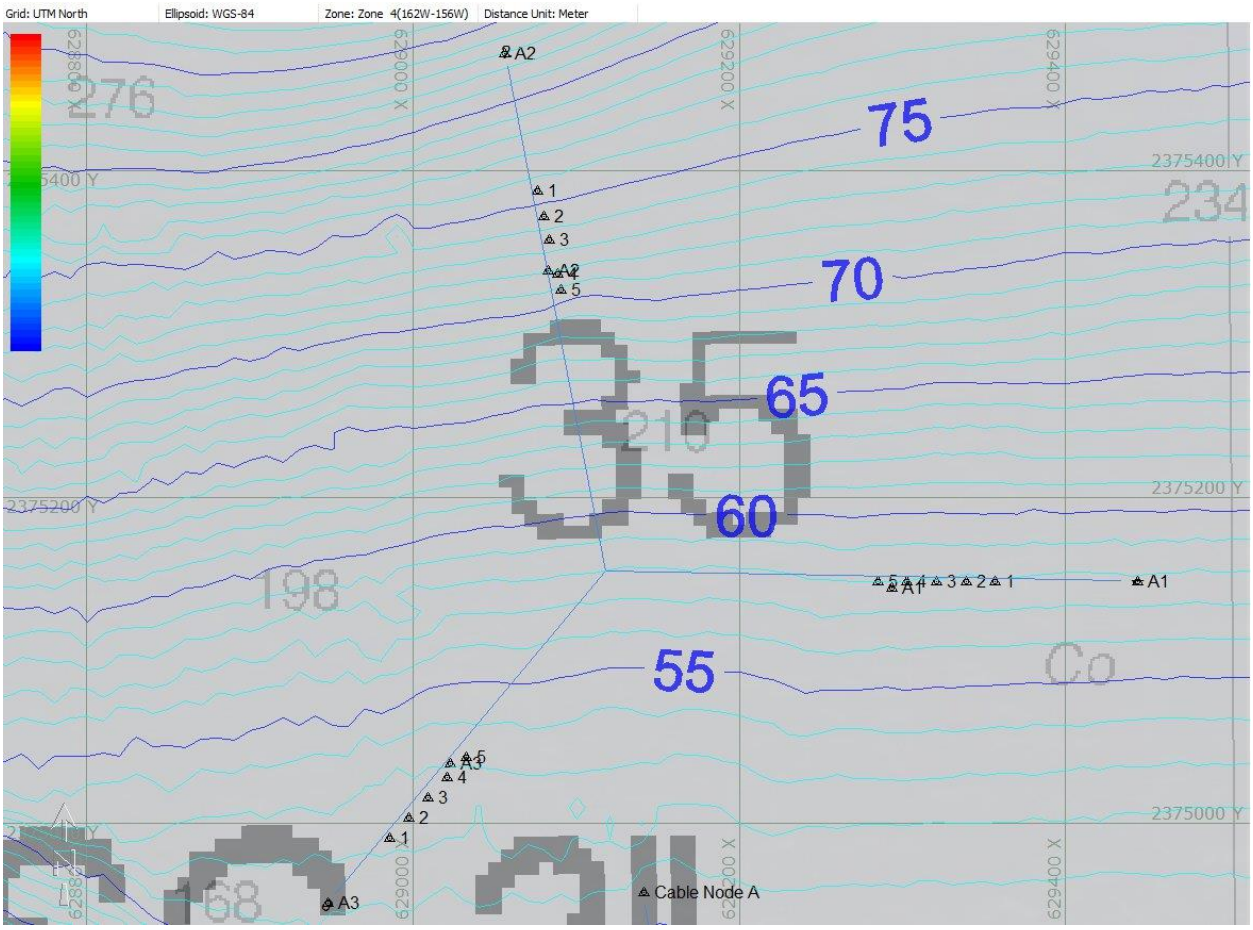

Figure 2-1 60m Site (A Moorings), Grid coordinates are UTM Zone 4, meters.

Figure 2-2 shows the positions of the mooring anchors, sinker weights and the surface floats for mooring legs B1, B2, and B3 at the 80m site.

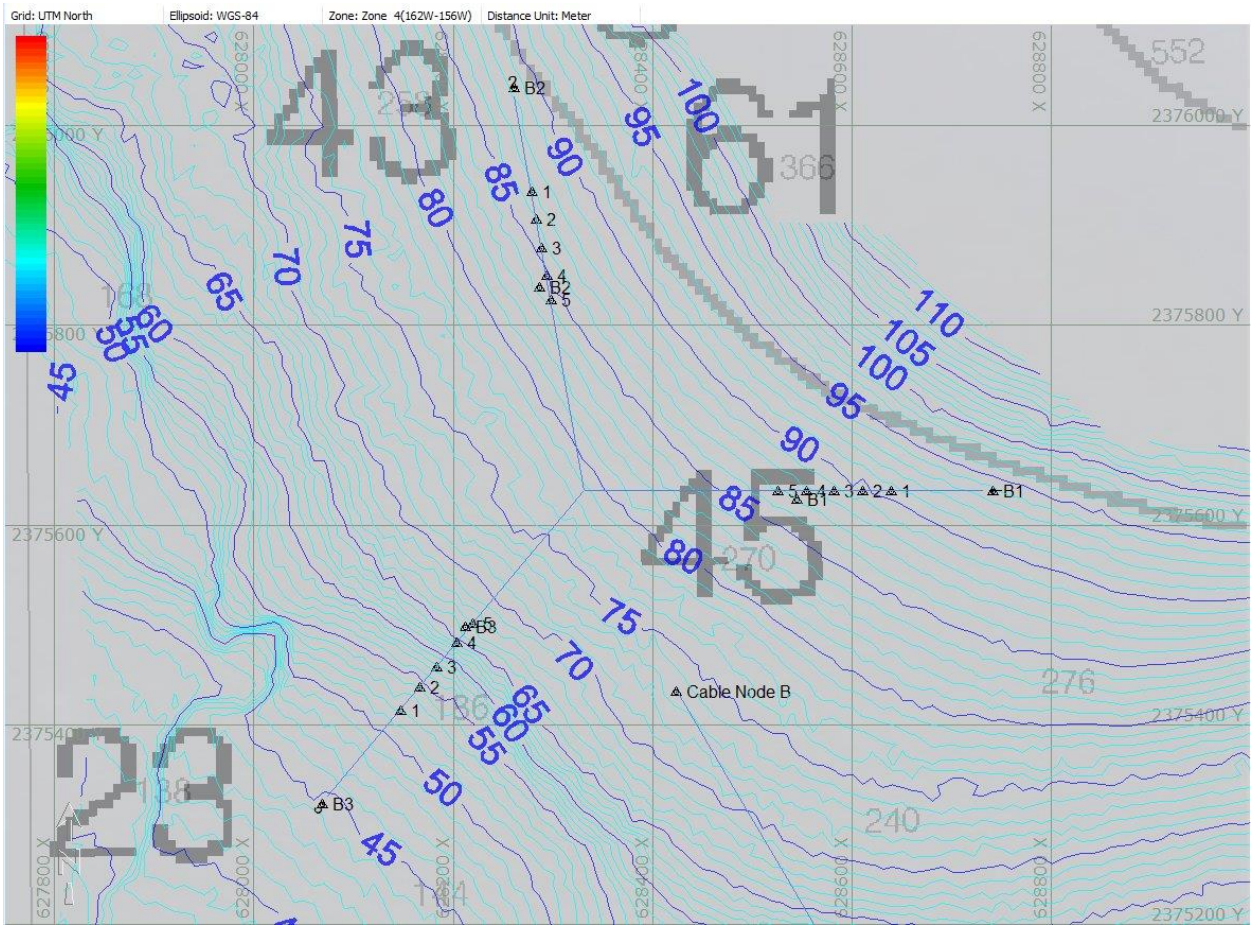

Figure 2-2 80m Site (B Mooring), Grid coordinates are UTM Zone 4, meters.

3. RESULTS

The configuration of the A and B mooring legs is shown in Figure 3-1, and Figure 3-2. There are 5 five sinker weights on each mooring leg. The sinker weights are numbered from the anchor to the surface float. Each mooring component has been given an identification number. Table 3-1 and Table 3-2 list the component type and dimensions. Components are identified by their mooring leg number and their individual component number. For example, the surface float on the A1 mooring leg is identified as A1-ML-14. Photographs of each of the mooring components are shown in Section 4.

The 60m site (A moorings) is currently occupied by the Fred Olsen Lifesaver WEC. Each of the three mooring legs is displacing the sediment in the area where the mooring leg interacts with the seafloor. The displaced sediment forms a trench with the mooring leg in the center (Figure 4-6 and Figure 4-30). The motion of each mooring leg chain has abraded the sinker weights (Figure 4-19 and Figure 4-27). The previous survey (Task 7D) found the fifth sinker weight (SW5) is detached on each of the A mooring legs and the fourth sinker weight (SW4) is detached on the A2 and A3 mooring legs. The present inspection confirmed the detachment of SW4 and SW5 and revealed that the third sinker weight (SW3) is detached on the A2 mooring leg. The sinker weights provide stiffness in the mooring system to reduce the watch circle of the WEC. The A1 mooring chain has a kenter link that is coming apart, a gap has formed between the two halves of the links that is (Figure 4-4).

A WEC device has not yet been moored at the 80m site. Each mooring chain hangs vertically under the surface float. There is little to no catenary in the chain. The motion of the B mooring legs displaces the sand and form a hole in the seafloor (Figure 4-37 and Figure 4-53). The B1 mooring chain is broken at the dip section of the chain. The B1 surface float has been temporarily secured to the B3 surface float. The end of the chain attached to the B1 surface float terminates with a link of chain without a stud (Figure 4-35). Also, the end of the chain attached to the B1 anchor also terminates with a link of chain without a stud (Figure 4-36). No remnants of a kenter link were found. A broken kenter link half would likely not have stayed attached to the end of the chain over the distance that the chain was drug to secure it to the B3 surface float. The fifth block on the B1 mooring leg was not found, all other blocks are attached.

The failed B2 mooring chain, sinker weights, and anchor (see 11/5/2016 Inspection report) were observed on the seafloor. The surface float was removed by Healy Tibbits. The B3 mooring leg is intact and all sinker weight are still attached.

The configuration of the power take off (PTO) chain baskets and bands at the A mooring site is shown in Figure 3-3 and Table 3-3. PTO 1 and PTO 2 were operational during the inspection. The intact components of the PTO 1 and PTO 2 systems are shown in Figure 4-63 through Figure 4-65 and Figure 4-66 through Figure 4-69, respectively. The link of chain attached to the underside of the PTO3 subsurface float failed (see previous Task 6K Report). The two remaining pieces of chain are piled together on the sea floor with the thimble and part of the riser line shown in Figure 4-73. There is a loop in the riser line that is an entanglement hazard to ROV operations shown in Figure 4-74.
A summary of the condition of each of mooring leg component is presented in Table 3-4.

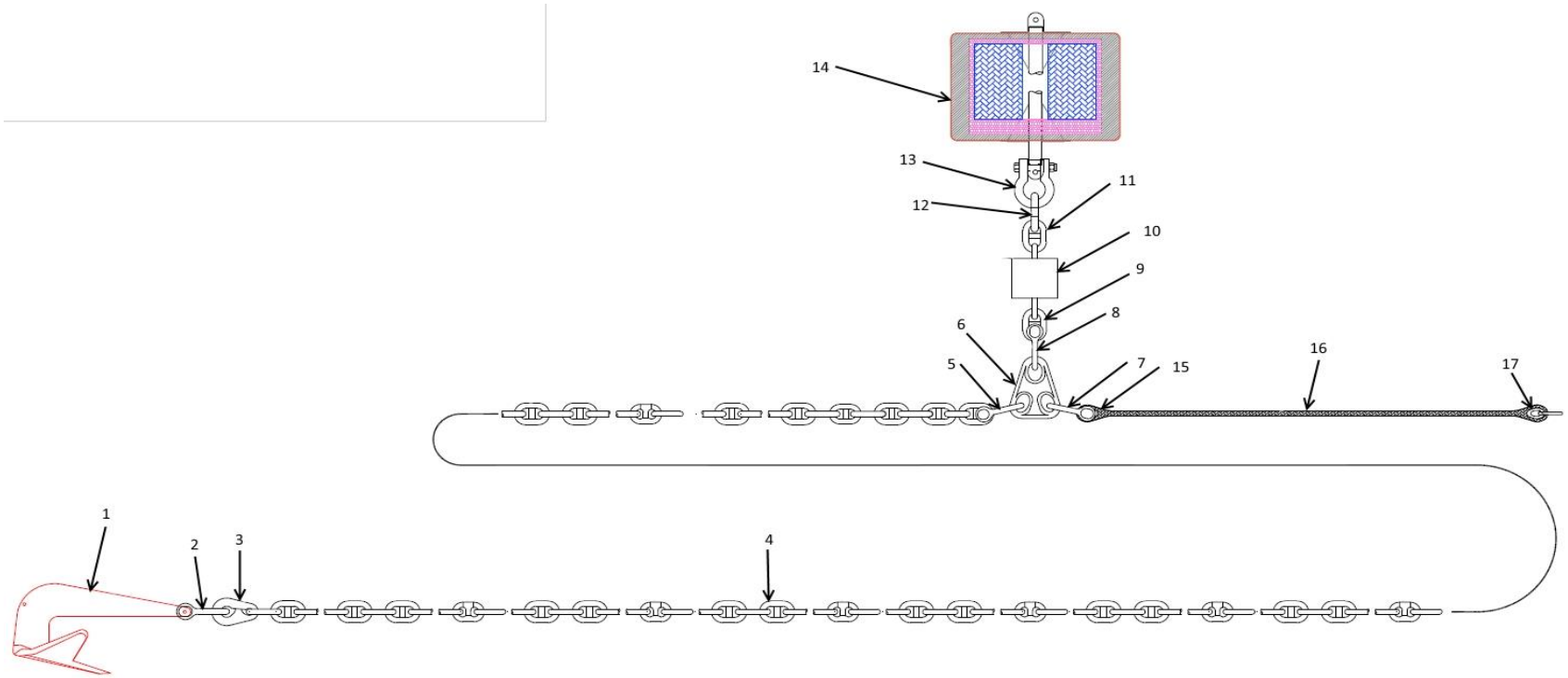

Figure 3-1 WETS 60m Site Mooring Leg

Table 3-1 WETS 60m Site Mooring Leg Components

Item	Component	Item	Component	Item	Component
ML-1	Bruce Anchor	ML-7	Marquip Tow Shackle, 2.75 in	ML-13	Safety Shackle, 3in
ML-2	Anchor Shackle	ML-8	Marquip Tow Shackle, 2.75 in	ML-14	Marine Fenders MB340
ML-3	Anchor Joining Link, 2.75 in	ML-9	ABS Grade 3 Chain 2.75 in	ML-15	10 in Tow Thimble
ML-4	ABS Grade 3 Chain 2.75 in	ML-10	Zinc Anode	ML-16	Plasma Line, 3.25 in 12x12
ML-5	Marquip Tow Shackle, 2.75 in	ML-11	ABS Grade 3 Chain 2.75 in	ML-17	11 in Tow Thimble
ML-6	Marquip Fish Plate 2.75 in	ML-12	Anchor Joining Link, 2.75 in		

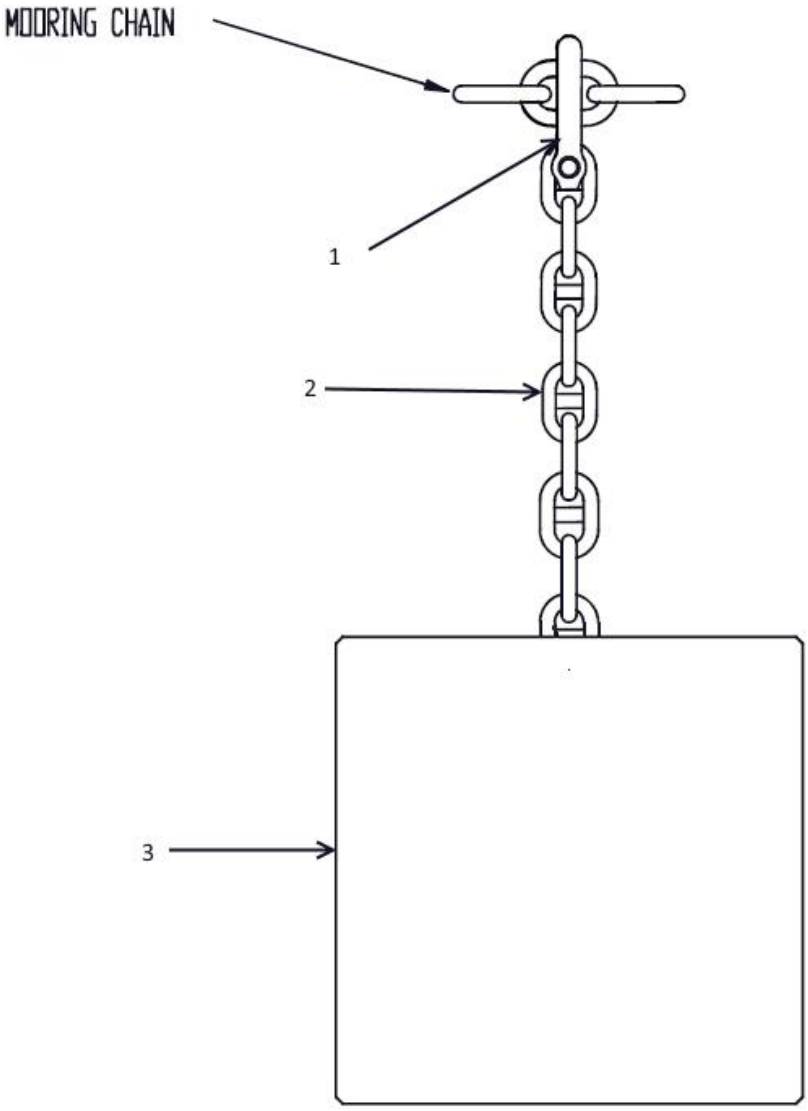

Figure 3-2 WETS 60m Site Sinker Weight Assembly

Table 3-2 WETS 60m Site Sinker Weight Components

Item	Component
SWx-1	Sinker Shackle
SWx-2	Stud Link Chain, 2.75 in
SWx-3	Concrete Block, 47in square

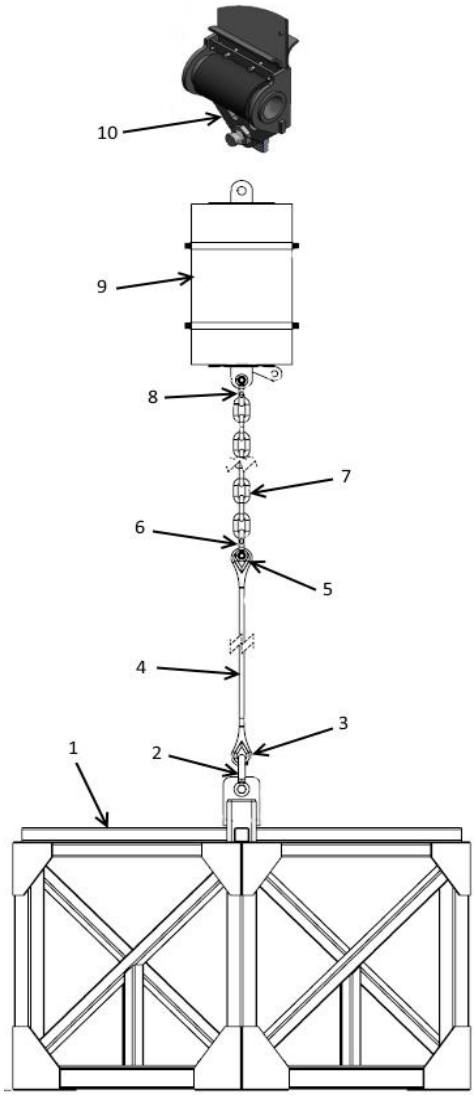

Figure 3-3 Fred Olsen Lifesaver Chain Baskets to PTO Bands

Table 3-3 Fred Olsen Lifesaver Chain Baskets to PTO Bands Components

Item	Component	Item	Component
PTOx-1	Chain Basket	PTOx-7	Open Link Chain, 1.25 in
PTOx-2	Safety Shackle, 1.75 in	PTOx-8	Safety Shackle, 1.375 in
PTOx-3	Heavy Duty Thimble	PTOx-9	Tension Bar Subsea Buoy
PTOx-4	Amsteel Blue, 1.375 in	PTOx-10	Band connector
PTOx-5	Heavy Duty Thimble	PTOx-11	Band (not shown)
PTOx-6	Safety Shackle, 1.375 in	PTOx-12	PTO Drum (not shown)

Table 3-4 WETS Deepwater Mooring Site Conditions

Site	Leg	Anchor (ML-1)	Sinker Weight 1 (SW1)	Sinker Weight 2 (SW2)	Sinker Weight 3 (SW3)	Sinker Weight 4 (SW4)	Sinker Weight 5 (SW5)	Dip section (ML-4)	Additional Comments
60 Mooring Site (Lifesaver)	**A1**	Both Flukes Buried	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth 2ft scour around block	Attached to ML-4 Dense marine growth with some voids near the chain attachment Block tilted on seafloor	Attached to ML-4 Rounded corners and wear due to ML-4 movement On edge of trench partial buried	Detached from ML-4 Block not found, Task 7D found SW5-1 parts on seafloor	Trench formed due to the movement of the ML-4 chain. Dip section starts at SW3 and continues to SW4.	Kenter link the section of chain (ML-4) with studs missing has a gap, looks abnormal.
	A2	Both Flukes Buried	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth with some voids near the chain attachment 1ft scour around block	Detached form ML-4 limited marine growth on WEC side of block, rounded corners and grooves from chain wear on top of block, block in the middle of trench	Detached form ML-4 Block has rounded corners and 20% loss of mass, sits in the center of the trench, Light marine growth	Detached form ML-4 Block has rounded corners, sits in the center of the trench with the ML-4 chain well above it Light marine growth	Trench formed due to the movement of the ML-4 chain extends from SW5 to SW2. Dip section starts at the third sinker weight (SW3),	Two loops of line are near the dip section of the A2 mooring chain. They are connected and have floatation (lift bag or crushed Norwegian Floats).
	A3	Both Flukes Buried	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 light marine growth, rounded corners and grooves from chain wear, Block in middle in of the trench	Detached form ML-4 Block has rounded corners and 25% loss of mass, block is buried on the outer edge of the trench	Detached form ML-4 Block has rounded corners and 50% loss of mass with exposed rebar, sits in the center of the trench	Trench formed due to the movement of the ML-4 chain, deepest part is between SW3 and SW4. Dip section starts at SW3. Chain (ML-4) lands on top of the block.	-
80m Mooring Site (vacant)	**B1**	Both Flukes Buried 0.5 ft scour on south side of exposed anchor	Attached to ML-4 Dense marine growth chain on top of block 1.0 ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block, void space under one corner of block	Attached to ML-4 Dense marine growth 1ft scour around block, void space under one corner of block	Attached to ML-4 Dense marine growth 1ft scour around block Block on its side	Detached form ML-4 Block not found, there is a hole in the area of where it should be and could be buried	Dip section is directly under the surface float. Chain (ML-4) ends with a single link missing a stud.	The B1 mooring chain is broken between SW4 and the section of chain that is missing it studs.
	B2	Both Flukes Buried	Attached to ML-4 Density marine growth 1.5ft scour around block	Attached to ML-4 Dense marine growth 1.5ft scour around block edge of block on chain (ML-4)	Attached to ML-4 Dense marine growth 1.5ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block	Attached to ML-4 Dense marine growth 1ft scour around block Block on the edge of a hole	Chain (ML-4) is broken at a kenter link on the approximately 20-25ft past the fifth sinker weight (SW5). B2 surface float was removed by Healy Tibbits Builders.	The end of the B2 mooring chain was a previously found to have a failed kenter link. This was not visible on this inspection.
	B3	Both Flukes Buried	Attached to ML-4 Density marine growth 1ft scour around block Chain (ML-4) on top of block	Attached to ML-4 Dense marine growth 2.0ft scour around block Chain (ML-4) on top of block	Attached to ML-4 Dense marine growth 1.0ft scour around block	Attached to ML-4 Dense marine growth 1.0ft scour around block	Attached to ML-4 Rounded corners on block Block in the hole under the subsurface float	Hole/sink is formed under the subsurface float.	-

All distances and mass percentages are visually estimated, green cells indicate functional components, green cells indicate failed components.

4. PHOTOGRAPHS

4.1 A1 Mooring Leg Components

Figure 4-1 A1-ML-(12,13,14)

Figure 4-2 A1-ML-(8,9,10)

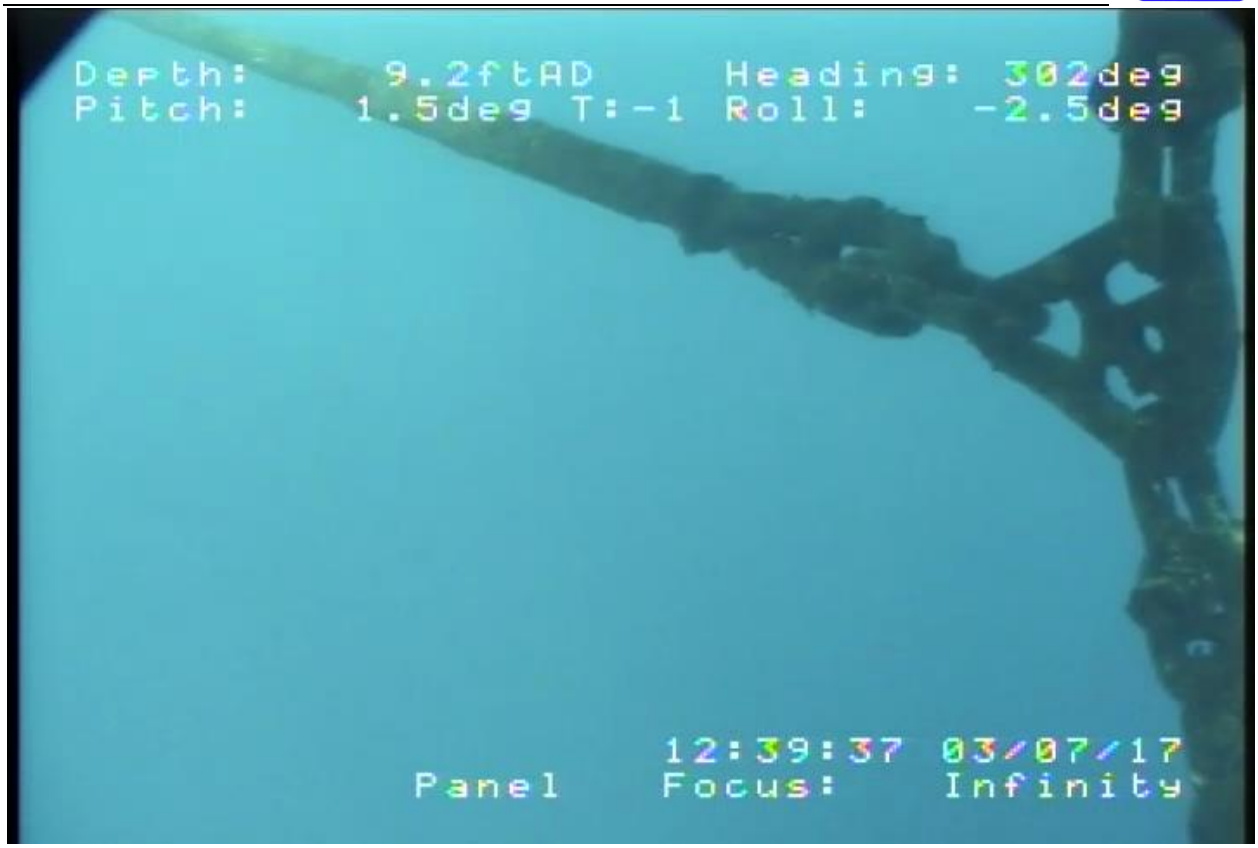

Figure 4-3 A1-ML-(5,6,7,8,15,16)

Figure 4-4 A1-ML-4 Kenter Link Gap

Figure 4-5 A1-SW4

Figure 4-6 A1-ML-4 Trench between SW4 and SW3

Figure 4-7 A1-SW3

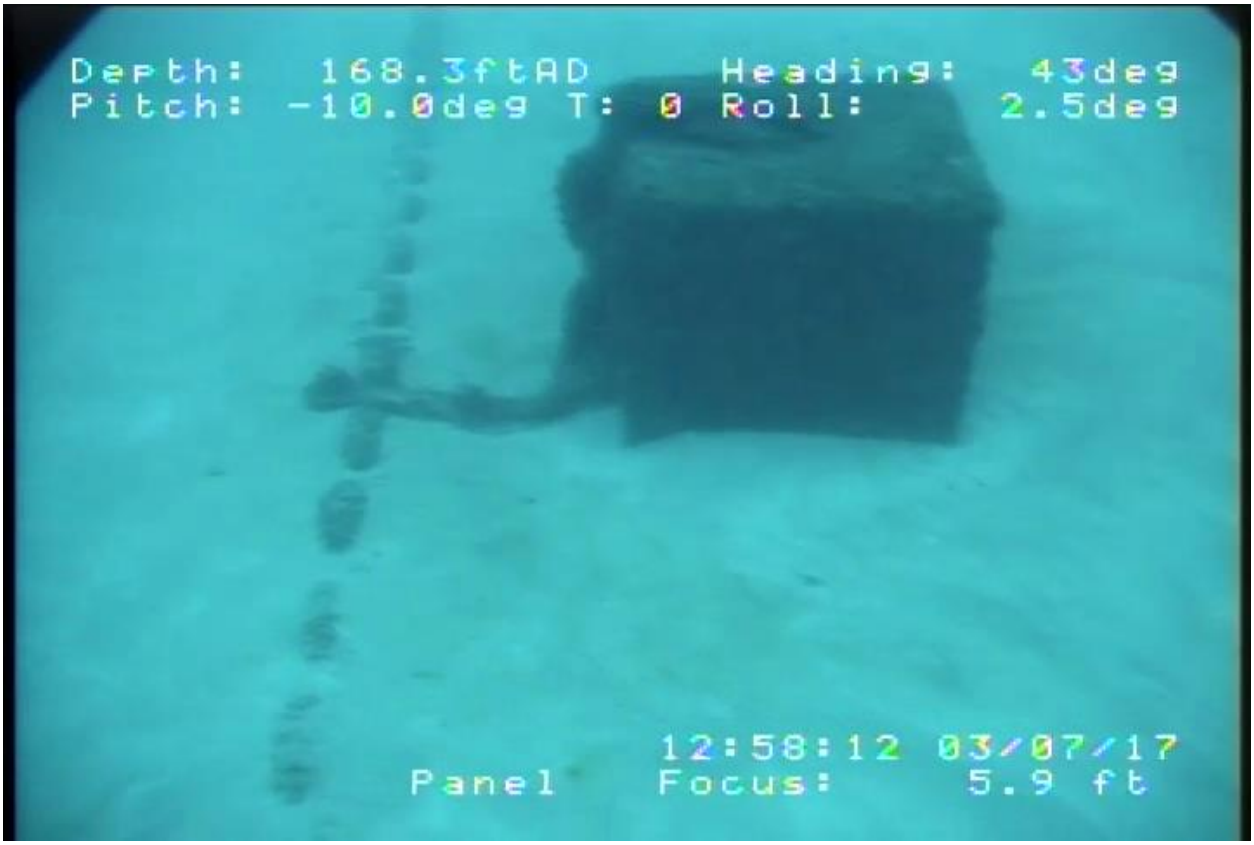

Figure 4-8 A1-SW2

Figure 4-9 A1-SW1

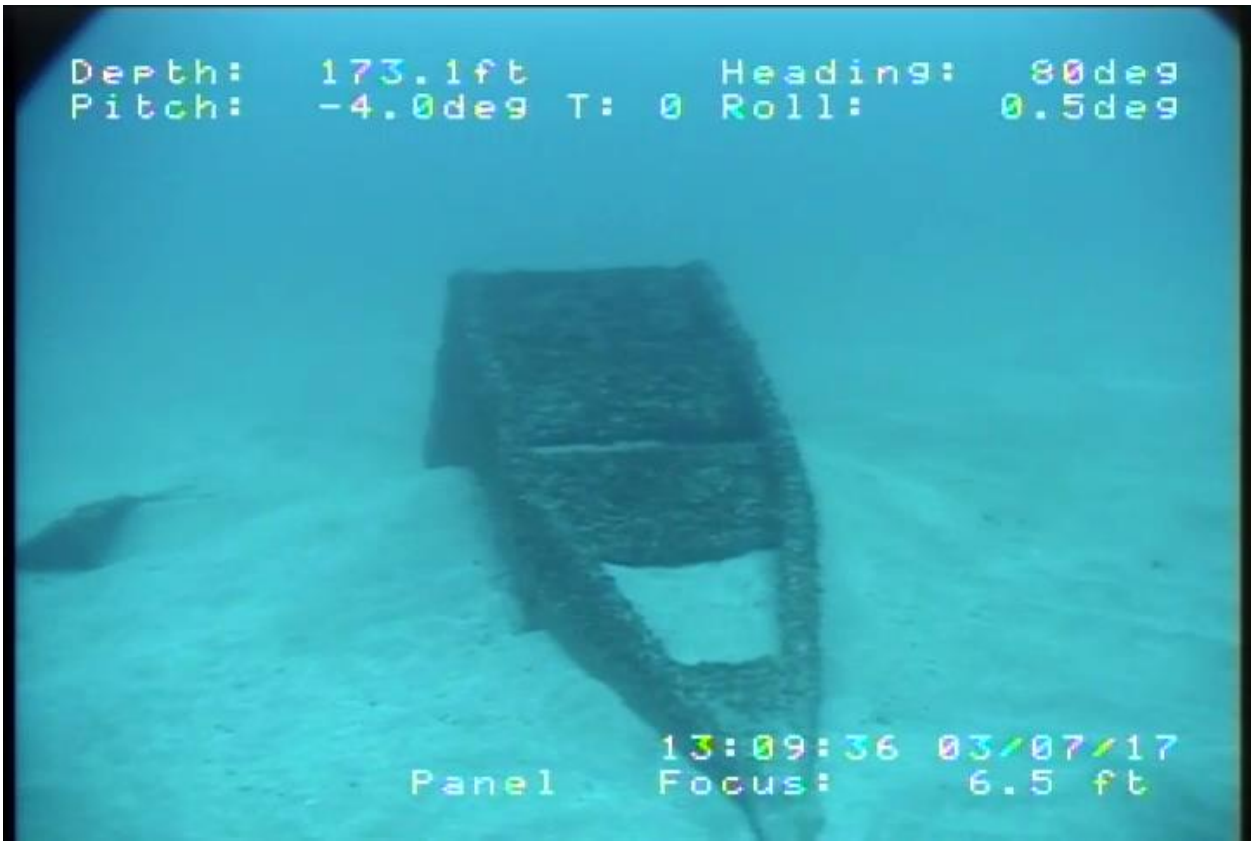

Figure 4-10 A1-ML-1 Anchor

4.2 A2 Mooring Leg Components

Figure 4-11 A2-ML-(11,12,13,14)

Figure 4-12 A2-ML-(8,9,10,11,12,13,14)

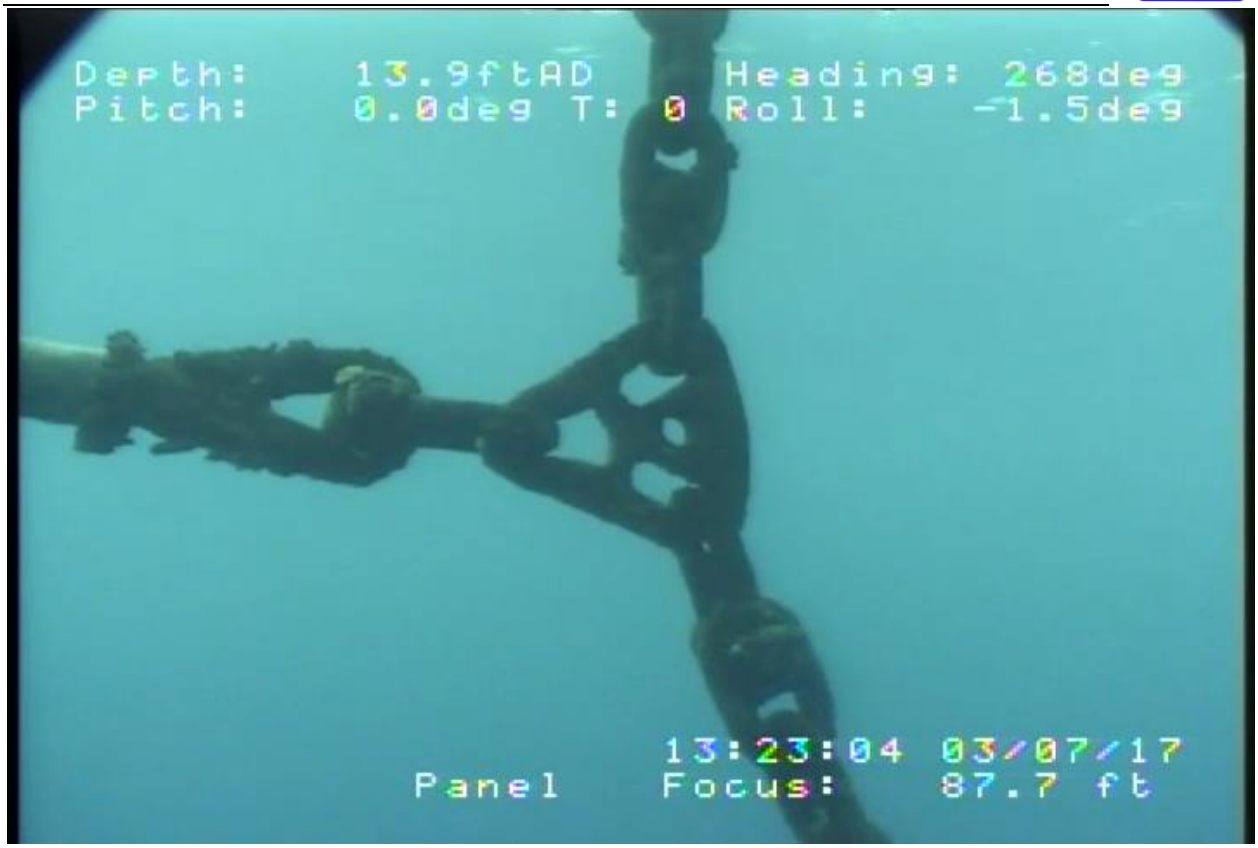

Figure 4-13 A2-ML-(4,5,6,7,8,9,15)

Figure 4-14 A2-ML-4 Missing Studs

Figure 4-15 Line Loop near A2 Dip Section

Figure 4-16 Smaller Line Loop near A2 Dip Section

Figure 4-17 Line on bottom near A2 Dip Section

Figure 4-18 A2-SW5

Figure 4-19 A2-SW4

Figure 4-20 A2-SW3-1

Figure 4-21 A2-SW3

Figure 4-22 A2-SW2

Figure 4-23 A2-SW1

Figure 4-24 A2-ML-1 Anchor

4.3 A3 Mooring Leg Components

Figure 4-25 A3-ML-(9,10,11,12,13,14)

Figure 4-26 A3-ML-(5,6,7,8,9,15,16)

Figure 4-27 A3-SW5

Figure 4-28 A3-SW4

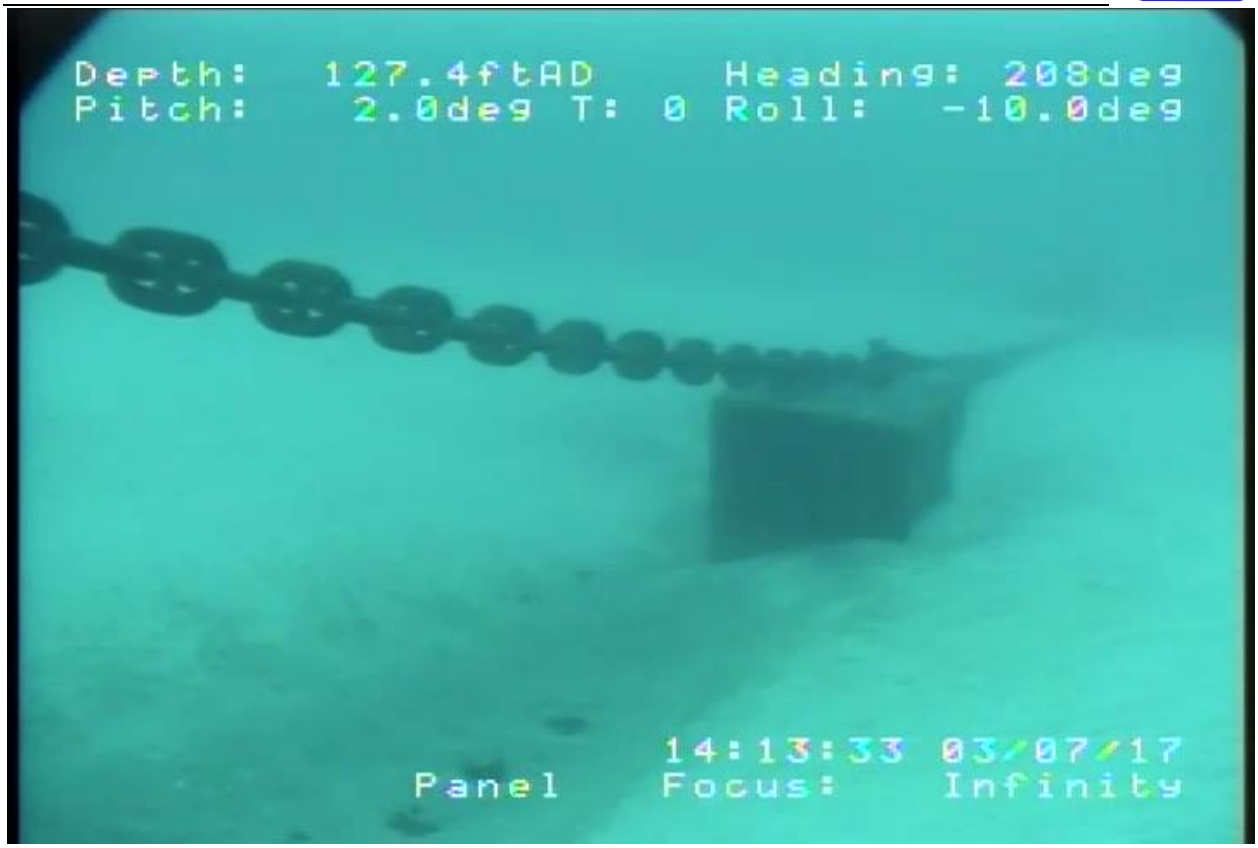

Figure 4-29 A3-SW3

Figure 4-30 A3-SW3

Figure 4-31 A3-SW2

Figure 4-32 A3-SW1


Depth: 120.5ftAD Heading: 220deg
Pitch: 6.5deg T: 0 Roll: -4.5deg
14:31:25 03/07/17
Panel Focus: 2.6 ft

4.4 B1 Mooring Leg Components

Figure 4-33 B1-ML-(9,10,11,12,13)

Figure 4-34 B1-ML-(5,6,7,8,9,15,16)

Figure 4-35 B1-ML-4 End of chain attached to surface float

Figure 4-36 B1-ML-4 End of chain attached to anchor

Figure 4-37 B1-ML-4 End of chain in hole

Figure 4-38 B1-SW4

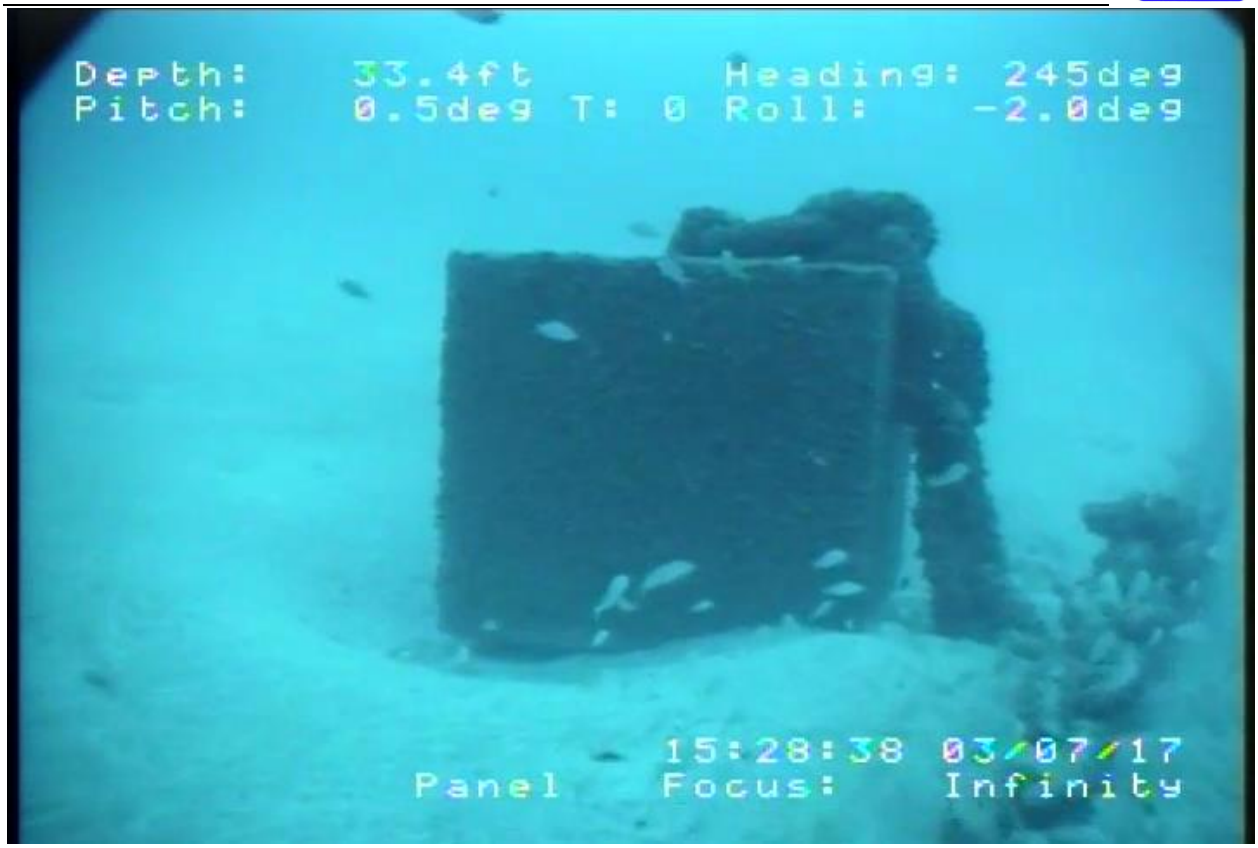

Figure 4-39 B1-SW3

Figure 4-40 B1-SW2

Figure 4-41 B1-SW1

Figure 4-42 B1-ML-1 Anchor

4.5 B2 Mooring Leg Components

Figure 4-43 B2-ML-4 End of Chain

Figure 4-44 B2-SW5

Figure 4-45 B2-SW4

Figure 4-46 B2-SW3

Figure 4-47 B2-SW2

Figure 4-48 B2-SW1

Figure 4-49 B2-ML-4 Cable

Figure 4-50 B2-ML-1 Anchor

4.6 B3 Mooring Leg Components

Figure 4-51 B3-ML-(11,12,13,14)

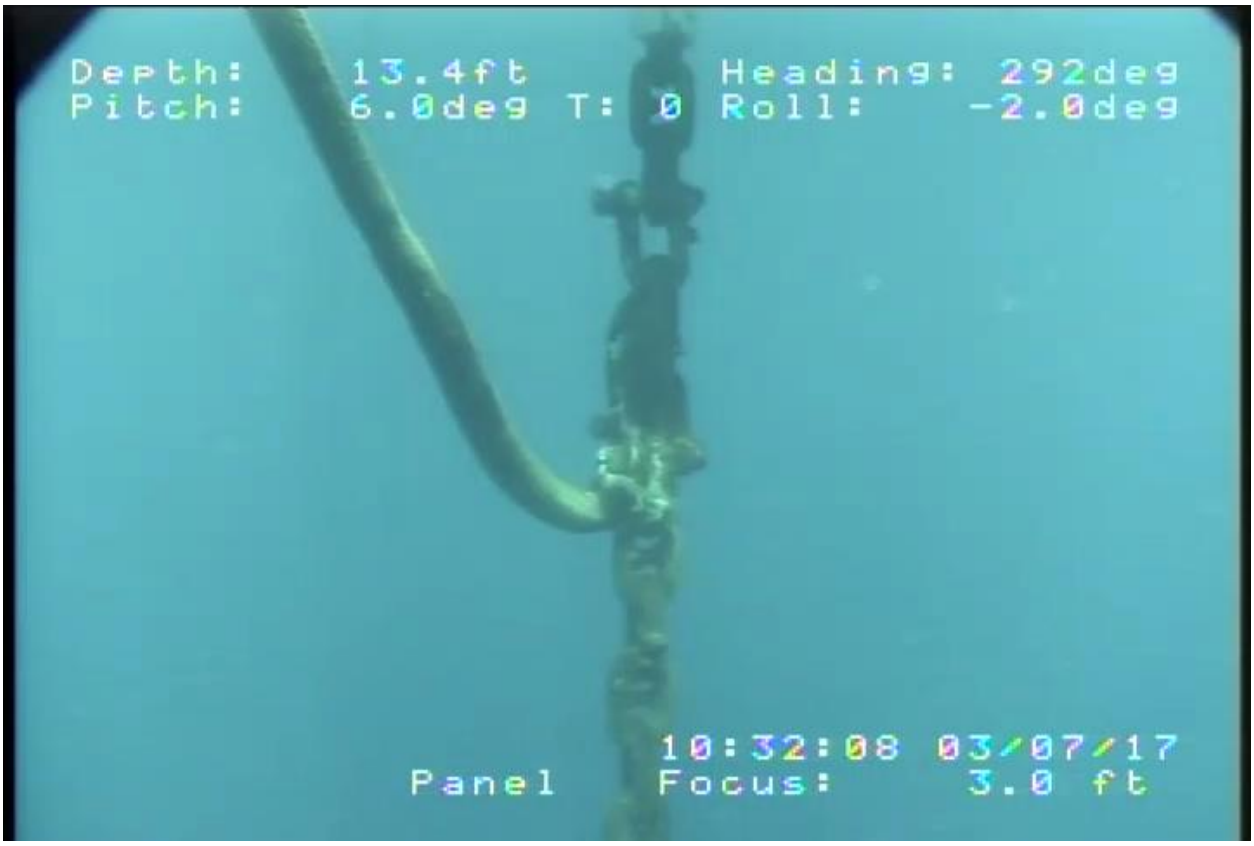

Figure 4-52 B3-ML-(4,5,6,7,8,9,10,11,15,16)

Figure 4-53 B3-ML-4 Missing Studs and Hole

Figure 4-54 B3-ML-4 Ray and Hole

Figure 4-55 B3-SW5

Figure 4-56 B3-ML-4 Kenter Link between SW5 and SW4

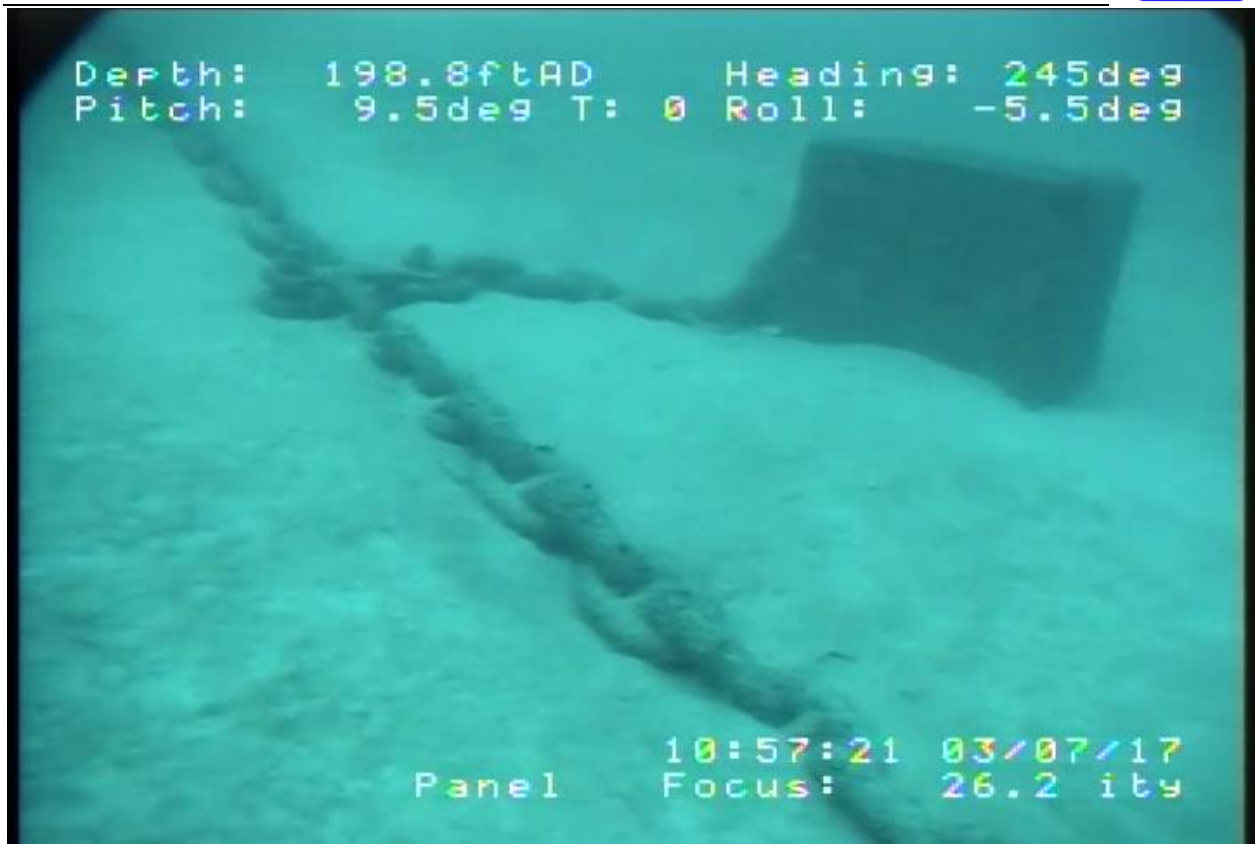

Figure 4-57 B3-SW4

Figure 4-58 B3-SW3

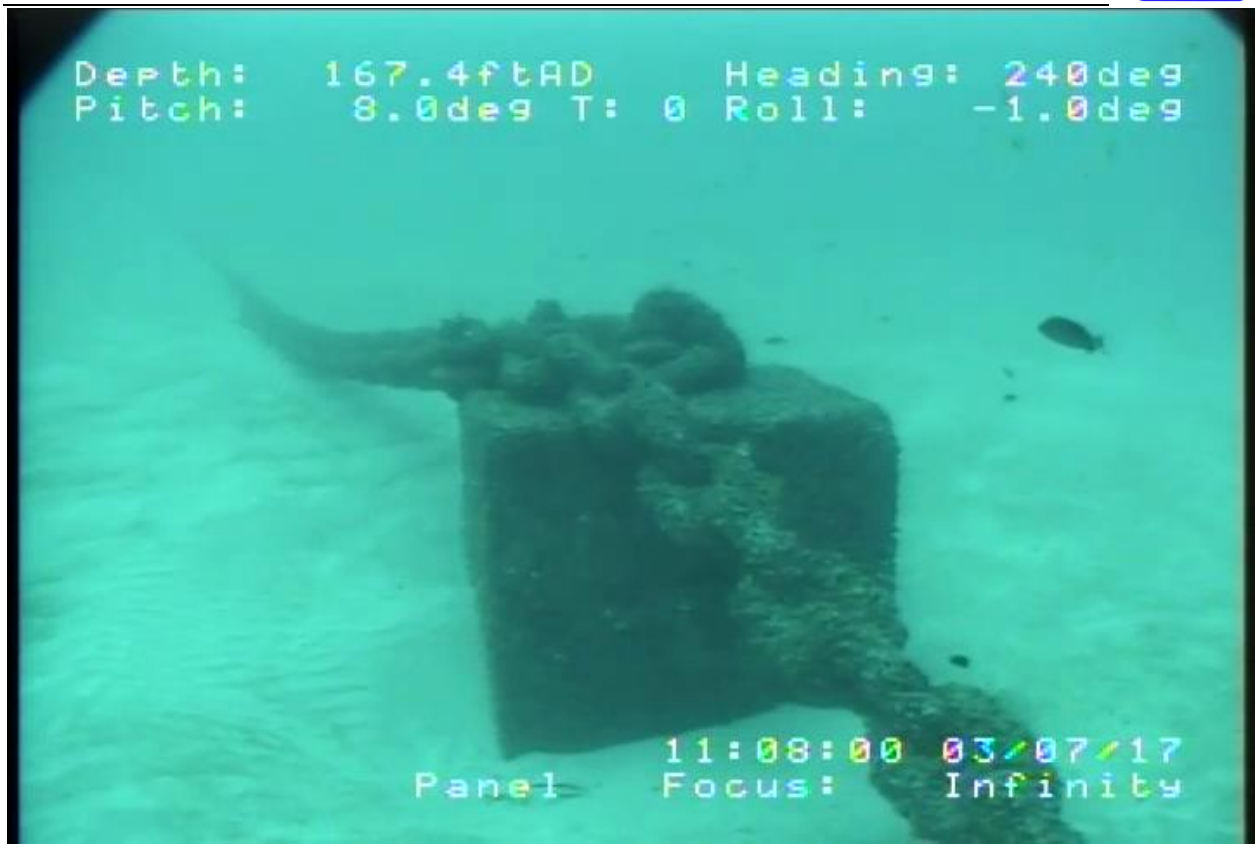

Figure 4-59 B3-SW2

Figure 4-60 B3-SW1

Figure 4-61 B3-ML-1 Anchor

4.7 PTO 1 Chain Basket

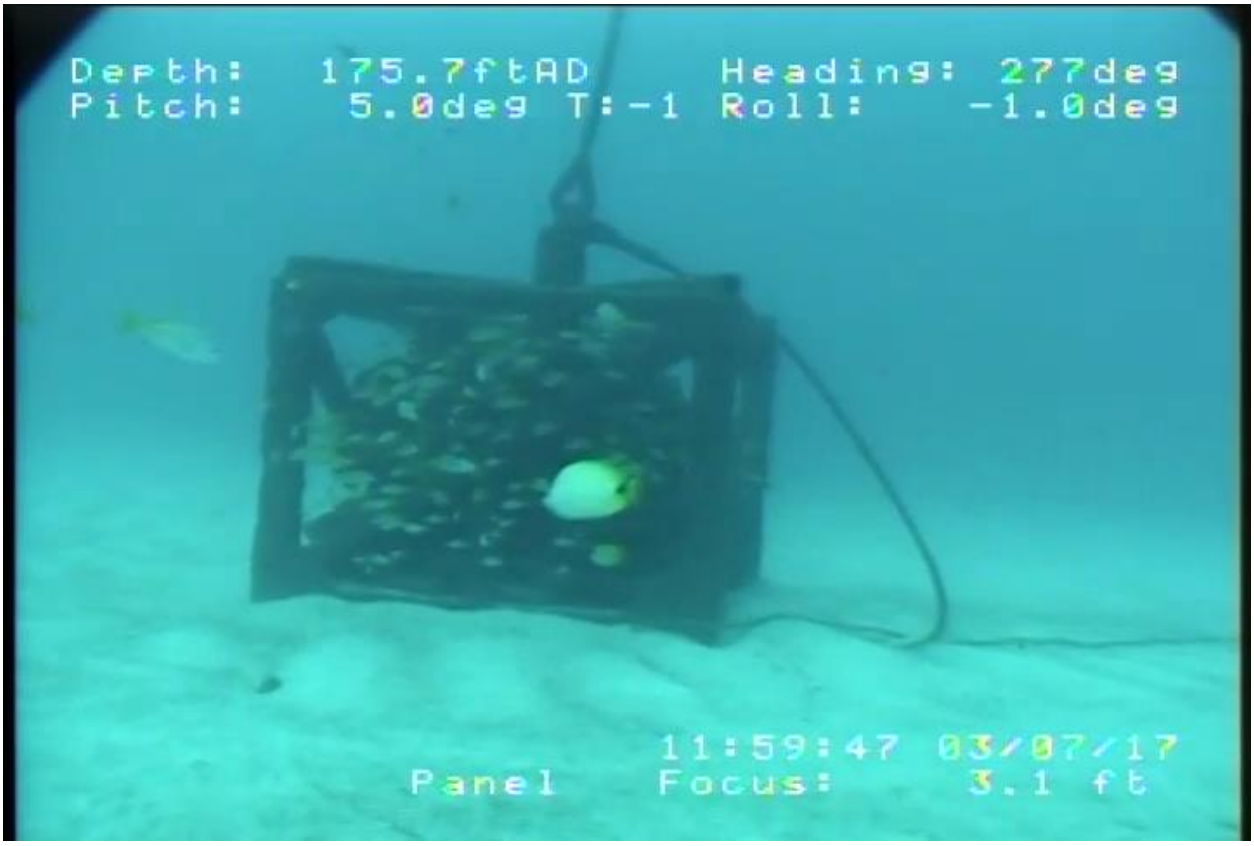

Figure 4-62 PTO1-1 Chain Box

Figure 4-63 PTO1 Recovery Wire

Figure 4-64 PTO1 Poly Recovery Line

Figure 4-65 PTO1-(1,2,3,4)

4.8 PTO 2 Chain Basket

Figure 4-66 PTO2-1

Figure 4-67 PTO2-(1,2,3,4)

Figure 4-68 PTO2 Thimble on Recovery Wire

Figure 4-69 PTO2 Recovery Wire

4.9 PTO 3 Chain Basket

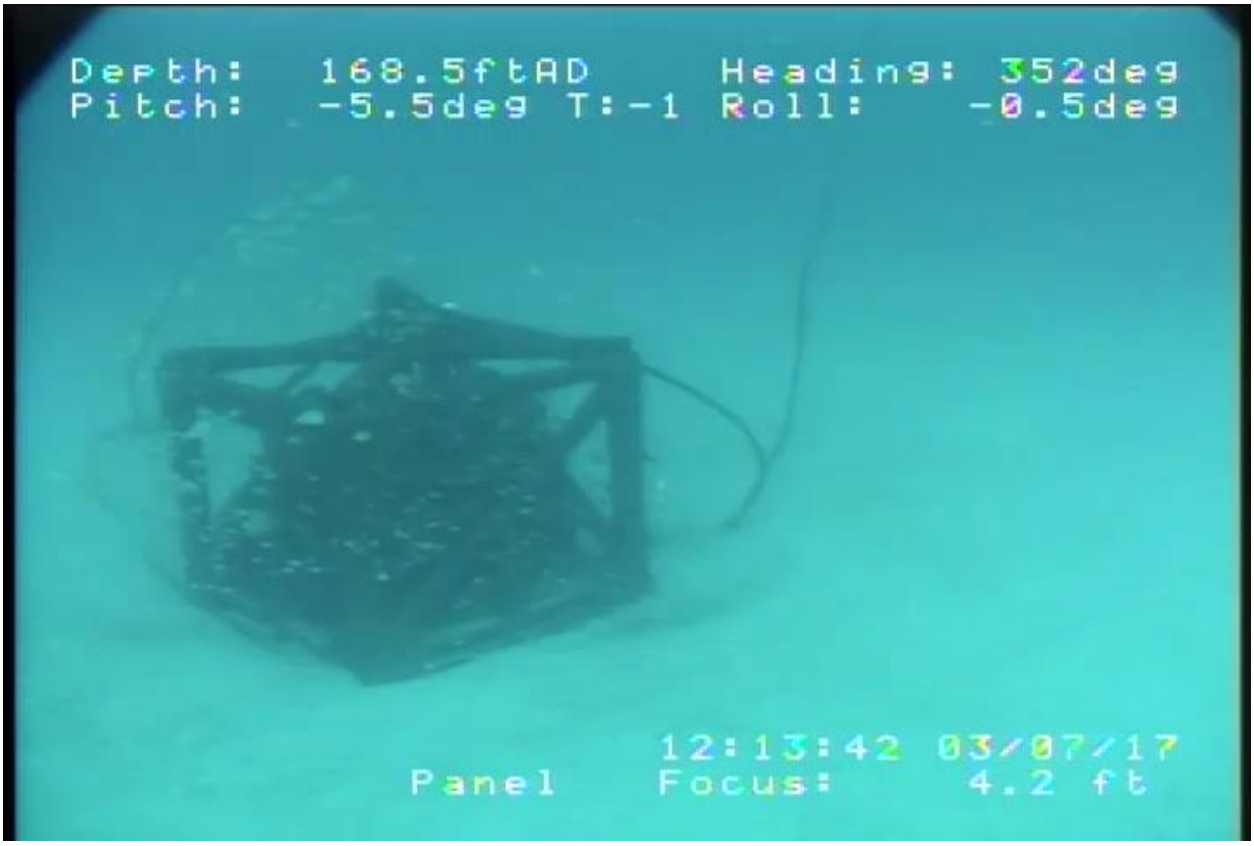

Figure 4-70 PTO3-1 Chain Basket

Figure 4-71 PTO3-(2-3)

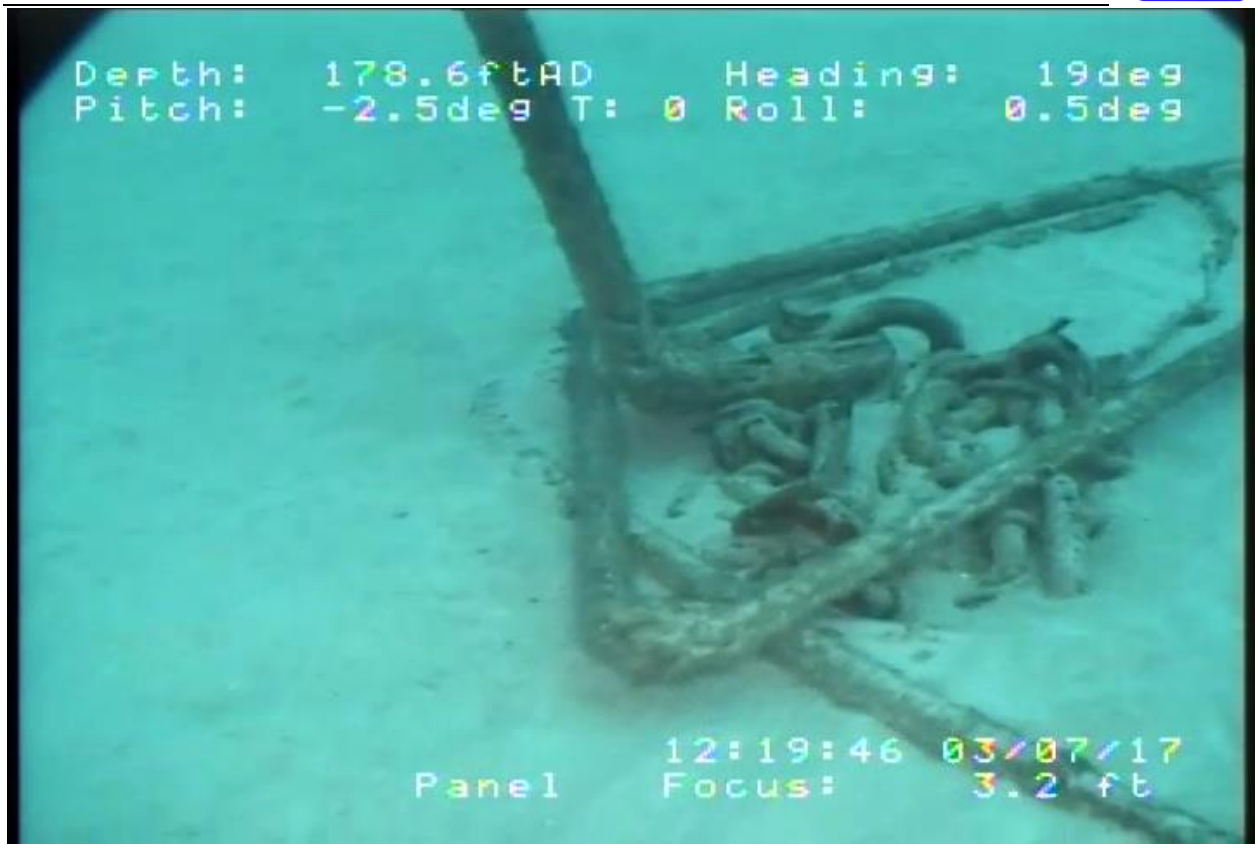

Figure 4-72 PTO3-(4,5,6,7)

Figure 4-73 PTO3-(4,5,6,7)

Figure 4-74 PTO3-4 Line Loop