Under Water Explosive Shock Testing (UNDEX) of a Subsea Mateable Electrical Connector, the CM2000

Matt Christiansen, SEACON Brantner & Associates Inc.

Abstract

The Under Water Explosive Shock (UNDEX) test is an important step in certification for submarine service. It demonstrates the ability of a component or system to withstand a near by underwater explosion as may be encountered in a field deployment without compromising function or safety. The UNDEX test exposes the device under test to a controlled underwater explosion of known force and orientation. The understanding of the set-up and test procedures encountered in the UNDEX test will help engineers to prepare for and design products able to withstand this testing and gain acceptance for use in military submarine service as well as in general oceanographic applications.

1. Introduction

Advancements in the technology of subsea-mateable connectors have enabled the development of increasingly sophisticated subsea systems and simplifies the installation logistics and construction of those systems. The operation and maintenance of such systems has also become much less expensive due to the availability of this technology. As with any new technology, it's acceptance into common use is enhanced by a thorough test and qualification program. The aim of such a program is to prove a product fit for purpose by accurately simulating the actual or even worst-case conditions the product will encounter in use. Exposure to explosive weapons is just such a "worst" case to be considered for systems operating on naval warships. Torpedo and mine damage experienced in World War I proved the danger posed by these weapons and efforts were made to understand the effects of under water explosions with model experiments. World War II was fought with more sophisticated weapons, and even non-contact explosive weapons were able to disable naval vessels [1]. Simulation and direct experimentation on the effects of underwater explosions are undertaken to demonstrate the ability of vessel structures and components to withstand these conditions [2]. The Under Water Explosive Shock Test (UNDEX) is such a test intended to certify components fit for use aboard fleet naval vessels. Passage of this and other environmental tests verify that a component will reliably perform the intended function while ensuring the safety of vessel and crew carrying that component or system.

The UNDEX test requirement and procedure as it was recently applied to the certification testing of the CM2019 subsea mateable electrical connector serves as an example of this test requirement. This program tested the component to MIL-S-901D, Grade "A" explosive shock as well as to Hydrostatic, Electrical, Vibration, Thermal Shock and Accelerated Life Testing.

1. The UNDEX Test

1.1 Introduction

The UNDEX test is specified in MIL-S-901D, requirements for shock tests, H.I. (hi-impact) shipboard machinery, equipment and systems [3]. This document is approved for public release and its distribution is not limited.

"The purpose of these requirements is to verify the ability of shipboard installations to withstand shock loading which may be incurred during wartime service due to the effects of nuclear or conventional weapons" [3].

A summary of the test specification as it pertains to Heavyweight UNDEX testing follows and is not intended to be all inclusive of the material presented in that specification.

Shock tests are broken down in a classification system by category, grade, class, type, and intended shipboard mounting location. The specification matches intended shipboard use to the appropriate test facility and equipment.

1) ***Category:*** There are three categories of testing based upon the weight of the item and fixtures. These are described in Table 1.

CATEGORY	TEST PLATFORM	WEIGHT LIMIT / DEFLECTION LIMIT
Light Weight	Light Shock Table	550 lbs. / 1 ½ in.
Medium Weight	Medium Shock Table	7400 lbs. / 3 in.
Heavy Weight	Floating Shock Platform (FSP)	60,000 lbs. [1]
	Large Floating Shock Platform	400,000 lbs.[2]

Table 1 - Shock Testing Categories

2) ***Grade:*** There are two grades applicable to shock testing based on the functional dependency on the test item.
   a. Grade A: For items that are essential to the safety and continued combat capability of the vessel.
   b. Grade B: For items not directly essential to safety and combat capability but which could become a hazard to personnel, to Grade A items or to the ship as a whole as a result of exposure to shock.

3) **Class***:* There are three class distinctions made on items subject to testing based on methods of mounting.
   a. Class I: Must meet shock requirement without the use of resilient mountings.
   b. Class II: Meets shock requirements with the use of resilient mountings.
   c. Class III: Must meet shock requirements with and without the use of resilient mountings due to shipboard applications that may use either mounting technique.

4) ***Type****:* Shock tests are further classified into three types by system level of assembly.
   a. Type A: Test of a principle unit directly supported by the ship structure.
   b. Type B: Test of a subsidiary component which is a major part of a principle unit and whose shock response is significantly affected by and significantly affects the shock response of the principle unit.
   c. Type C: Test of a subassembly that is part of a subsidiary component or a principle unit whose shock response is significantly affected by the shock response of those units but does not significantly affect the shock response of those units.

[1] Weight limit subject to height of center of gravity, reference Fig. 5 in MIL-S-901D [1].
[2] Weight limit subject to height of center of gravity, reference Fig. 6 in MIL-S-901D [1].

5) **Mounting Location:** Mounting location is further classified for surface and submarine vessels. Items are classified according to their mounting on the Hull, Deck, Shell, or Wetted Surface of a vessel.

6) **Mounting Plane:** The mounting plane is further classified according the mounting plane of the item under test. Mounting planes being defined as the Base, Back, Front or Top of the item. Provision is made for combinations of more than one plane, and for mounting not described by the above classifications.

7) **Mounting Orientation Aboard Ship:** The mounting orientation aboard ship further classifies a test item in accordance with its preferred orientation aboard ship. This is defined by the shaft, front face, principle axis or other primary feature of the item being parallel to or perpendicular to the fore-and-aft axis of the ship.

1.2 Shock Requirements

The requirements presented within the specification are provided as a guide to general shock test criteria and to aid in selecting the detailed shock test requirements to be applied to a specific item. Items may pass shock testing either by direct testing of the item in question or by extension of previously tested items as provided for within the specification.

1) **Wet Mounted Items:** All items subjected to shock testing that will be mounted to the shell of the vessel or are wet mounted below the water line must be subjected to heavyweight shock testing utilizing a Floating Shock Platform (FSP). These items will be attached to the underside of the FSP and mounted such that the item is exposed to the direct explosive pressure wave during the test.

2) **Mounting:** The specification governs the mounting of test items to the shock platform and requires that in cases of multiple mounting options, the option considered dynamically to be \the most severe (usually the stiffest) be used. Yielding or cracking of the test fixture itself during shock testing is not acceptable unless it can be demonstrated that this failure does not reduce the validity of the test on the principal test item. Fasteners used to secure test items to test fixtures must conform to MIL-S-1222. Fasteners external to the primary test item may be re-tightened between test shots if it can be demonstrated that loosening of the fasteners is due only to "seating" of the fixtures and that the fasteners have not yielded from the shock load. If this cannot be demonstrated the test continues without re-tightening of the external fasteners.

3) **Simulation of attachments:** In cases where attachments to the primary test item may significantly affect the response of the test item, such as attached piping or motors, those items must be considered and simulated in the test application. The specification governs application of dummy loads to the test assemblage.

1.3 Shock Application

With the test item secured to the underside of the FSP, the FSP is moored in a fixed location within the shock test facility. An explosive charge is suspended below a buoy at a fixed depth below the water surface and at a horizontal distance referred to as the "standoff" distance from the FSP. This is defined as the distance from the centerline of the charge to the near face of the FSP. An initial "shock" is applied from a fore-or-aft direction relative to the FSP to "seat" the test fixtures.

Three more "shocks" are applied from an athwartship direction relative to the FSP, each closer to the FSP than the previous shot and therefore more severe. See Table 2 for Heavyweight UNDEX test schedule.

TEST CONDITIONS	STANDARD FSP	LARGE FSP
Charge Depth	24 feet	20 feet
Explosive Charge (weight / composition)	60 lbs./HBX-1	300 lbs./HBX-1
Shot Direction:		
Shot 1	Fore-and-Aft	Fore-and-Aft
Shots 2, 3, and 4	Athwartship	Athwartship
Standoff Distance:		
Shot 1	40 feet	110 feet
Shot 2	30 feet	80 feet
Shot 3	25 feet	65 feet
Shot 4	20 feet	50 feet

Table 2 - Shock Test Schedules

1.4 Shock Monitoring

It is intended that items be subjected to shock testing while in their normal operating condition. In particular, Grade A items are to be tested while operating in each of their normal operating modes, positions, and conditions.

In general, for items with many possible operating conditions, it is acceptable to test the three most significant operating conditions judged to be most severe for shock application, unless otherwise specified. For example, motors would need to be tested while running at rated speed and at standstill.

1.5 Acceptance Criteria

Performance of items under test must be monitored during the shock to the extent necessary to verify compliance with the test acceptance criteria. Monitoring instrumentation is not specifically required if it is not necessary for adequate verification. The test item and fixture are to be visually and functionally inspected after each shock. After the last shock, a final disassembly of the tested item and inspection for breakage, deformation, or misalignments is conducted. Any failures being cause for rejection in a Grade A item. It is preferred that this post test inspection be conducted at the test site in order that any discrepancies discovered may not be attributed to subsequent damage in transport.

a. Grade A items must come through this testing without unacceptable degradation of performance and without creating a hazard to ship or personnel. Momentary malfunctions are acceptable only if automatically self-correcting and do not result in any further malfunction of the item.

b. Grade B items do not need to be functional after exposure to shock but must not come adrift or create a hazard to ship, crew, or Grade A items and must not release any harmful substances or create a fire hazard.

1.6 Quality Assurance

Contractors supplying items to be subjected to shock testing are responsible for defining all performance and inspection criteria and to have these criteria documented and approved by the accepting authority. All shock tests performed in accordance with MIL-S-901D must be conducted at an approved shock testing facility and must be witnessed by a designated government representative.

This representative must witness the shock test as well as all inspections and functional verifications. The witness will certify all reported test reports and information. The accepting authority will convey approval of shock test compliance in a format specified within MIL-S-901D identified as Figure 19 in that specification.

1.7 Additional Notes

Details of administration, reporting, and acquisition requirements are noted within the specification. Also noted are definitions of conditions and references made to applicable drawings of test equipment and mounting fixtures. There is a listing of general considerations offered as guidelines to design of shock tolerant assemblies.

2. The Connector

2.1 Description

The assembly undergoing UNDEX testing as described in this paper is an underwater mateable electrical connector intended for use on various classes of United States Navy submarines. The connector is a prototype configuration of standard connector components and design features tailored to a specific application. The connectors are as described by SEA CON drawing BT13-103 for the bulkhead connector and BT13-102 for the plug connector. These are nominally identified as CM2019/2mm connectors and are based upon the CM2000 connector technology developed by Lockheed Martin and SEA CON® [4].

The electrical contacts are 2mm gold-plated beryllium copper bonded to Polyetheretherketone (PEEK) insulators. The socket contacts are enclosed within concentric oil filled compensating bladders of natural rubber for dual electrical isolation. These contacts are housed in Monel shells utilizing a Nickel-Aluminum-Bronze coupling nut. The connector unit is rated for service to 1000 VAC at 10 Amps. The CM2019/2mm is a subsea mateable connector and is qualified for operation to 2000 psi by this program. Note that previous test programs have qualified the CM2000 contact assemblies for service to 10,000 psi [6].

2.2 Configuration:

The connector set is configured as an in-line connector pair with 19 electrical circuits and is intended to be molded onto a jacketed cable. The bulkhead side houses the isolated socket contacts and mounts into a ¼" thick bulkhead with an integral shell-key for anti-rotation and orientation within the mounting bulkhead, reference Figure 1 and Figure 2.

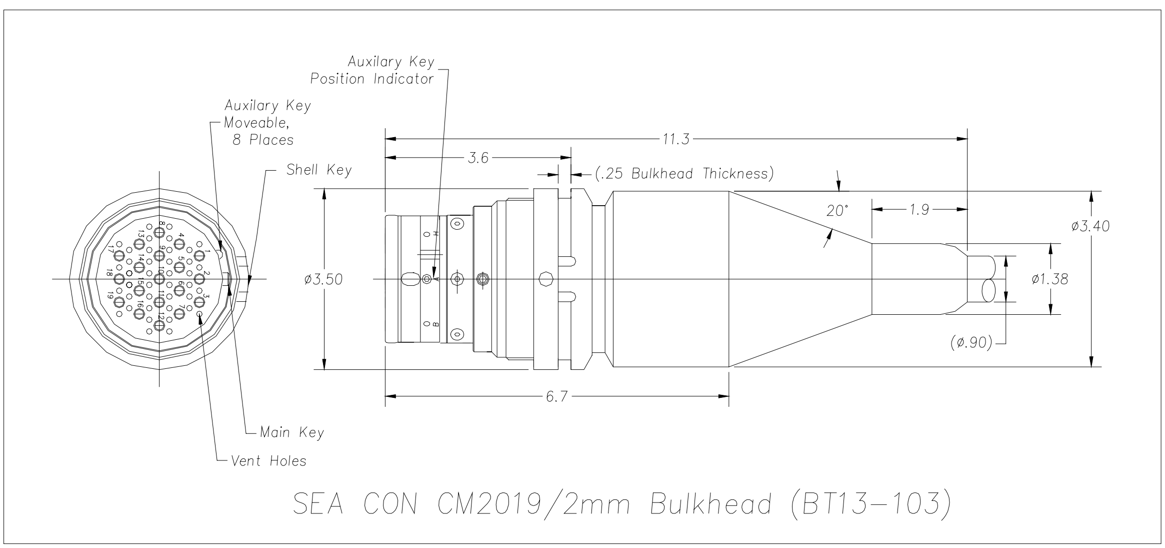

Figure 1 – CM2019/2mm Bulkhead Connector

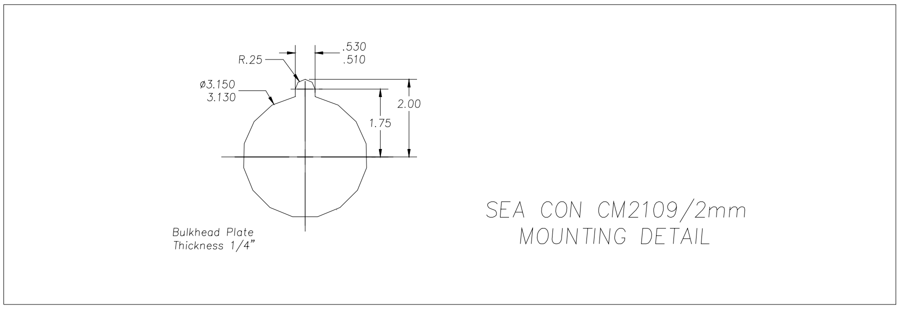

Figure 2 - CM2019/2mm Mounting Detail

The plug connector houses the pin contacts and coupling nut. Reference Figure 3. Both halves of the connector pair have provision for full 360° coupling of cable shielding to shells in order to meet military Hazards of Electromagnetic Radiation to Ordinance (HERO) requirements. This plug connector features a main fixed key and a secondary moveable key, which is field configurable to one of 8 unique key combinations. The bulkhead connector has a field configurable secondary keyway allowing for the same 8 unique key combinations. This feature provides for eight uniquely mateable connector configurations while necessitating the logistical support of only one stock connector item.

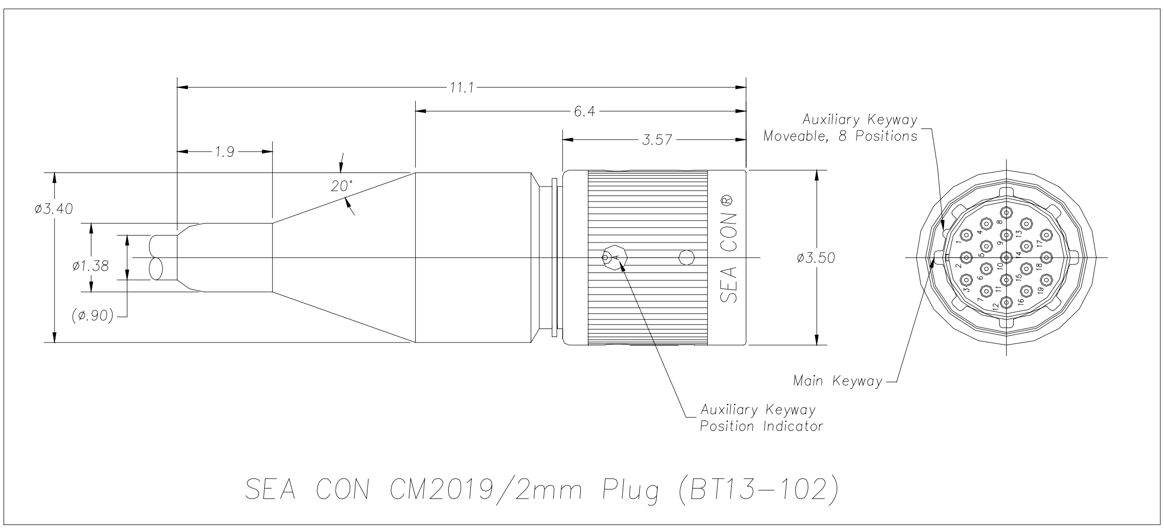

Figure 3 - CM2019/2mm Plug Connector

2.3 Cable and Molding:

The connector is molded to cable manufactured to MIL-C-915/48 as modified to NAVSEA Drawing 6292767, which is a multi-pair cable with shield within a polyurethane jacket. The cable is molded to the connector using polyurethane molding compound and procedures in accordance with the NAVSEA molding manual [5]. The cable length is to be 20 feet from each side of the connector pair so that the ends of the cables may be brought to the topside of the FSP for functional testing of the mated connector pair during testing.

2.4 Manufacturer:

The connector and molded cable assemblies were manufactured by SEA CON® / Brantner & Associates, specifically, SEA CON® PHOENIX in Westerly, Rhode Island, USA.

3. The Test Program

3.1 Introduction

As mentioned earlier, the CM2019 connector was designed for a specific application and intended use aboard various classes of the United States Navy submarine fleet. For this application the connectors are to be wetted-surface mounted external to the pressure hull. The cables and assemblies will not penetrate the pressure hull. Per MIL-S-901D, the connectors used in this manner must be accepted for use by passing Hi Impact Shock Tests (UNDEX) using the heavyweight test method, on the standard Floating Shock Platform (FSP).

3.2 Classification:

For this application it is determined that the plug/bulkhead connector pair are classified as, and will be tested to Grade A, Class I, Type A UNDEX testing [7].

3.3 Additional Testing:

The UNDEX test does not fully simulate the environmental conditions a connector for this application will experience. The CM2019 connector will be further subjected to a full physical and environmental test program designed to qualify it for service in the intended application. This testing will include:

- HERO testing, per MIL-STD-167 (Hazards of Electromagnetic Radiation to Ordinance)
- Vibration testing, per MIL-STD-167
- Radiated Emissions / Susceptibility, per MIL-STD-461
- Cable Seal Flexing, per Method 2017 of MIL-STD-1344

Additionally the connector design will be subjected to an Accelerated Life Test (ALT) program consisting of the following requirements:

- Equivalent 4 year test, saltwater exposure
- Elevated temperature exposure in air, 66°C for 31 hours
- Elevated temperature exposure in saltwater, 66°C for 350 hours
- Extreme temperature cycling in saltwater, 66°C to 6°C for 33 cycles
- Pressure cycling, 0 to 500 psi for 10 cycles
- Pressure exposure, 1000 psi for 45 hours
- Mating cycle testing, 200 mates and de-mates in and out of water

The connector test program was started with the UNDEX test as it was deemed to be the most demanding of the tests to be completed. This paper focuses on this UNDEX test and its results. Additional information on the above test sections will be available from the manufacturer and will be reported in the future.

4. The Test Set-Up

4.1 Facility:

The UNDEX test of the CM2019 was undertaken at a land based test facility in a basin at Dynamic Testing Inc. (DTI) located in Rustburg, Virginia. The test was combined with other programs and equipment for logistics of cost and scheduling. The combined weight of all equipment to be tested allowed for the standard FSP to be used and the standard heavyweight shock schedule of test charge and standoff distances was used (reference table 2).

4.2 Fixtures:

A fixture as described by Figure 4 was constructed to hold the bulkhead connector and mounted to the underside of the standard Floating Shock Platform (FSP).

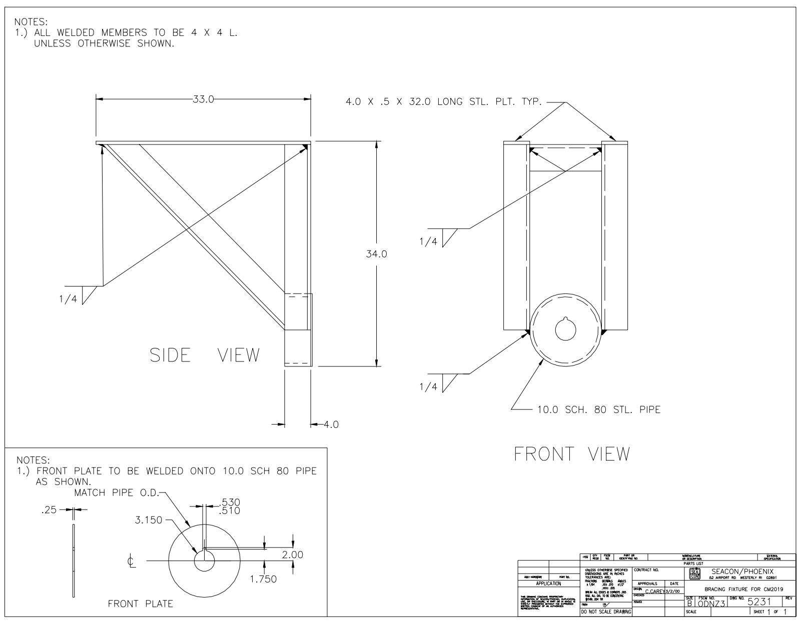

Figure 4 - CM2019/2mm UNDEX Mounting Fixture

The plug connector mounts by mating to the bulkhead connector and is secured by means of an integral coupling nut. The far-ends of the attached cable lengths were brought out of the water to the top of the FSP and kept dry for access to the electrical contacts of the connector set for functional testing as described by Figure 6.

4.3 Instrument Locations:

The connector fixture was mounted so as to align the connector axis parallel to the Fore-and-Aft axis of the FSP in simulation of the actual mounting conditions to be encountered in a submarine installation. The resultant depth of the connector location was approximately 7 feet below the water line. The FSP was instrumented with two pressure transducers, two accelerometers, and one velocity meter during the tests in order to monitor and record the actual shock environment created by the explosive charges. The transducer calibration data is included as an appendix to the shock test report [8]. These transducers were located as described in table 3.

TRANSDUCER	LOCATION	ORIENTATION
Acceleration 1	Blast side, athwartship centerline on FSP bulwark rail	Vertical
Acceleration 2	Blast side, athwartship centerline on FSP bulwark rail	Athwartship
Velocity	Blast side on FSP inner-bottom [3]	Vertical
Pressure 1	On adjacent equipment fixture at depth	N/A
Pressure 2	On adjacent equipment fixture at depth	N/A

Table 3 - Transducer Locations

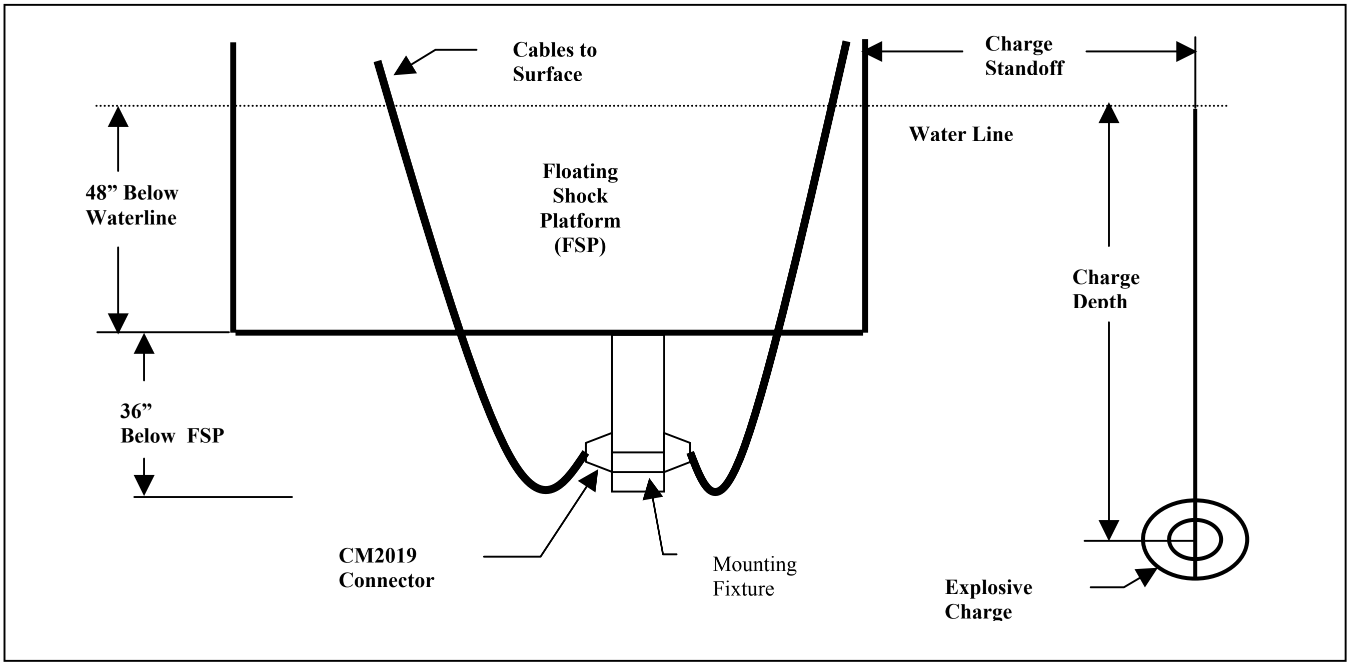

Figure 6 - UNDEX Test Set-up

4.4 Test Equipment:

As a passive electrical device the connector is to be tested for operational integrity on the basis of the individual contact continuity and insulation resistance (IR) between adjacent contacts and inner cable shielding (note that this inner cable shielding was coupled to the connector shells within the connector assembly). Acceptable function was deemed to consist of the following:

Continuity readings of 0.4 Ohms or less for each connector circuit including all attached cabling and test leads, measured with an ISOTEK Low OhmMeter.

[3] Velocity meter mounted on fore-aft centerline for shot 1 and moved to athwartship centerline for shots 2 through 4.

Insulation Resistance (IR) readings of 500 Meg Ohms or greater between all connector circuits and to the cable shielding / connector shells measured with a General Radio model 1864 Meg OhmMeter.

5. THE TEST RESULTS

5.1 Introduction

The connector was mounted to the fixture on the FSP as described and operational integrity verified before the FSP was placed in the basin of the UNDEX facility. Shot 1 was conducted as required and the FSP removed from the basin for inspection and verification of operational integrity. This sequence was repeated as required for shots 2, 3, and 4. In each case, in addition to verification of operational integrity, the connector and fixture were inspected for any damage, deformation, or de-lamination that may have occurred.

In each inspection and verification after the shock trials the connector and fixture were found to be without defect. The operational integrity remained at original levels without degradation. As such the connector assembly was deemed to have passed successfully the UNDEX Hi-Impact Heavyweight Shock Test requirement [8].

5.2 Characteristic Shock Energy:

The actual levels of shock environment experienced in these tests are of a sensitive nature and will not be reported in this publication but may be found in the referenced shock test reports [8 and 9]. Without putting values to parameters recorded during the shock events, Figure 5 schematically represents the shock environment experience.

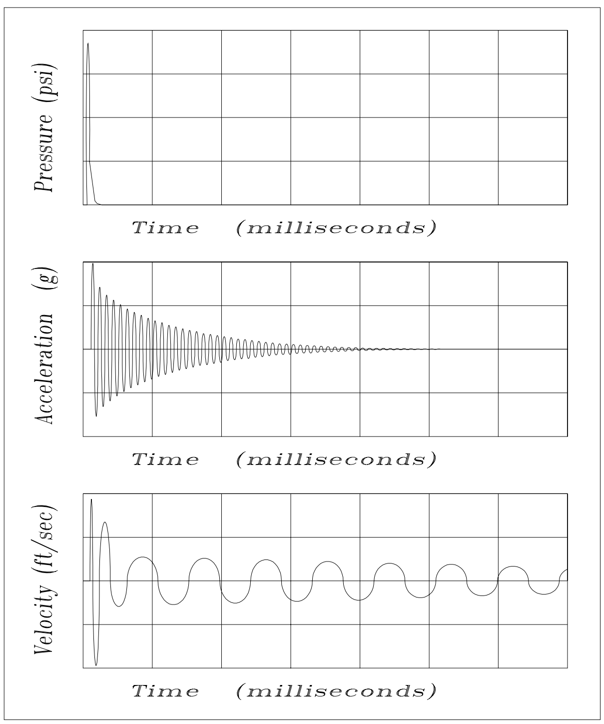

Figure 5 - Characteristic Shock Responses

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