OYSTER 800 PROJECT

STANDARD BOLTED CONNECTIONS

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General Background

Aquamarine Power Ltd (APL) was a wave energy company responsible for developing a wave energy converter called Oyster. The Oyster system consisted of a Wave Energy Converter (WEC) located in shallow water close to the shore, with a bottom-hinged flap which oscillated due to wave action. Double acting pistons on each side of the WEC pumped water through a high-pressure pipeline back to shore, where high pressure water drove a Pelton wheel turbine connected to an electrical generator. The flow from the Pelton wheel discharged to a header tank and returned to the WEC via a low-pressure return pipeline.

APL deployed a full-scale 315 kW Oyster 1 system at the European Marine Energy Centre (EMEC) in August 2009, followed by a second-generation machine rated at 800kW, Oyster 800, in August 2011.

APL ceased trading in November 2015, and the intellectual property was acquired by Wave Energy Scotland (WES), who propose to share relevant documents and information acquired with developers in the WES programme and the wider sector.

Background to this Document

One area of concern at APL was the long-term integrity of mechanical connections on Oyster 800, a device which included a number of bolted and flanged connections of various sizes and functions. Operational experience shows that mechanical connections are prone to both corrosion and loosening, caused primarily by vibration.

This document was produced by APL in 2014 to summarise good practice in the specification of bolted connections on the Oyster 800 device, particularly with respect to the material selection and assembly techniques. This document was informed by experience gained through operation, and the offshore maintenance campaigns during the summers of 2013 and 2014. The standard applications considered in this document are structural connections, hydraulic flanges, retaining fasteners, jacking screws and hydraulic fittings.

Introduction

Oyster 800 was installed at EMEC over 2011 to 2012 before undergoing a series of commissioning and operating trials. One area of concern was the long-term integrity of mechanical connections on the machine. There are a number of bolted and flanged connections of various sizes and functions. Operational experience shows that mechanical connections are prone to both loosening, caused primarily by vibration, and also corrosion.

The purpose of this document is to outline guidelines for good practice in various applications of threaded connections, specifically with respect to material selection and assembly techniques. The standard applications considered in this document are as follows:

1a. Structural Connections
These are applications in which threaded fasteners are used to transfer loads across an interface. They are typically used where it is not feasible to make a welded connection, possibly due to reasons of material compatibility, or because there is a need for disassembly during the operational life of the equipment. The fasteners are tightened to create a compressive preload in the joint, which then carries operating loads through a combination of cyclic compressive stress and friction. The size of fasteners used for structural connections in Oyster 800 varies from small M6 connections attaching instrument housings to very large M64 fasteners holding major structural components such as the flap and bearing shafts together.

1b. Hydraulic Flanges
These are applications in which pressure retention is achieved through a joint comprising of two flanges, a gasket and a number of threaded fasteners. The purpose of the fasteners is to compress the gasket to provide a seal, and also to preload the joint to withstand the internal (hydrostatic) separating forces, as well as any external structural loads on the system. Most commonly, these are specified as standard (e.g. ASME) connections although a range of different standards are in use on Oyster, as well as a small number of proprietry connections. The size of fasteners used on the hydraulic flanges ranges from M16 (on the installation ballast system)up to M39 (on the 14" HP lines).

1c. Retaining Fasteners
In applications where relatively modest structural loads need to be transmitted, threaded fasteners are sometimes used without necessarily preloading the joint. The fasteners therefore transmit loads directly in shear and tension. This sort of connection is generally inadequate to resist significant reversing loads, but may be used in areas such as control and instrumentation or in connections where there are alternative load paths for the significant loads, such as cylinder pins. These bolts can be of any size.

1d. Jacking Screws
This is a special application in which a threaded fastener is used in compression to position or release one component with respect to another. They are loaded only temporarily, either as a one-off operation or intermittently for example during maintenance. These can be almost any size. For example, the largest jacking screws used on Oyster 800 were M110 to retain the machine on the piles during grouting.

2. Hydraulic Fittings
There are a number of hydraulically actuated valves on Oyster 800. A synthetic esther fluid is used at pressures of up to 210 bar and distributed through a series of hoses and fittings of between 1/4" and 3/4" in size. A variety of different connection types are currently in use. Some of these are permanent connections and some need to be disconnectable for maintenance. There are also some small hydraulic fittings such as bungs and needle valves connected to the main Oyster 800 hydraulic system for commissioning and maintenance purposes. These are not traditional fastener systems and so are dealt with separately.

Mechanical Fastener Matrix

This sheet covers structual connections, hydraulic flanges, retaining fasteners and jacking screws.

These are the standard fastener systems which are proposed:

Connection Materials	Case	Description
Base case offshore connection - with CP	A	Lubricated (Molykote 1000), bright zinc plated (Zn5) property class 8.8 bolts and property class 8 nuts with stainless steel 316 Nord-lock washers, bare metal mating faces
Critical connections - no/uncertain CP	B	Lubricated (Molykote 1000), duplex stainless steel bolts and nuts with 254 SMO Nord-lock washers, bare metal mating faces
Low consequence connection - no/uncertain CP **NON PREFERRED - try to use A or B**	C	Lubricated (Molykote 1000) grade A4-80 stainless steel bolts and nuts with stainless steel 316 Nord-lock washers, bare metal mating faces
Offshore connection with CP - low strength substrate material	D	Lubricated (Molykote 1000) bright zinc plated (Zn5) property class 8.8 flange head bolts and property class 8 flange nuts with stainless steel 316 'SP' Nord-lock washers, bare metal mating faces
Low tension offshore connection	E	If bolt tension must be less than 30% of yield, use appropriate scheme as per A, B, C or D but replace Nord-lock washer with prevailing torque locking (e.g. Nyloc nut)
Base case onshore connection	F	Lubricated (Molykote 1000), hot dip galvanizsed property class 8.8 bolts and property class 8 nuts (plus hardened washers if necessary)
Onshore connection with restricted access (e.g. header tank)	G	Lubricated (Molykote 1000) grade A4-80 stainless steel bolts and prevailing torque (e.g. Nyloc) nuts plus stainless steel 316 Nord-lock washers if tightening tension is above 30% of bolt yield

These are the standard fastener systems which are recommended for use in the following areas, for the following substrate materials:

Location	Application	Substrate Material					
		Carbon steel	SGI	Duplex SS	316L	GRE	HDPE
Onshore	Structural connection	F/G	F/G	F/G	F/G	F/G	F/G
	Hydraulic flange	F/G	N/A	F/G	F/G	F/G	F/G
	Retaining fasteners	F/G	F/G	F/G	F/G	F/G	F/G
	Jacking screws	F/G	F/G	F/G	F/G	F/G	F/G
Offshore - submerged with CP	Structural connection	A/D	D	A	D	D/E	D/E
	Hydraulic flange	A/D	D	A	D	D/E	D/E
	Retaining fasteners	A/D	A/D	A	A/D	A/D	D/E
	Jacking screws	A/D	A/D	A	A/D	A/D	D/E
Offshore - submerged but no CP	Structural connection	B	N/A	B	B	B/E	B/E
	Hydraulic flange	B	N/A	B	B	B/E	B/E
	Retaining fasteners	B	N/A	B	B	B/E	B/E
	Jacking screws	B	N/A	B	B	B/E	B/E
Offshore - splash zone	Structural connection	B	B	B	B	B/E	B/E
	Hydraulic flange	B	N/A	B	B	B/E	B/E
	Retaining fasteners	B	B	B	B	B/E	B/E
	Jacking screws	B	B	B	B	B/E	B/E

The tightening method recommended for assembly of these joints is as follows:

Tightening Method	Method	Description
Torque tightening - target **60%** of fastener yield strength for structural connections	1	Generally up to M24 (Highest torque with calibrated torque wrench and torque multiplier to be used is 750Nm) but could be larger for specific cases and hydraulic tooling.
Torque tightening - target **50%** of fastener yield strength for flange connections	2	Generally up to M27 (Highest torque with calibrated torque wrench and torque multiplier to be used is 750Nm) but could be larger for specific cases and hydraulic tooling.
Bolt tensioning	3	Only used for large, HP flanges and heavy structural connections. Specific consideration of bolted connection design is recommended before using bolt tensioning

At present, a wide range of fastener sizes are in use on Oyster. In future, it would be helpful to reduce this variety. Unless there are strong technical reasons to use different sizes, the following guidelines should be followed:

Preferred Sizes*		Grade 8.8 tension capacity (at yield)
Smallest fastener to be exposed to offshore or onshore (external) environments	M12	54kN
Smallest fastener intended to be installed or removed by divers	M16	100kN
Preferred medium structural connection fastener	M24	233kN
Preferred heavy structural connection fastener	M36	539kN
Preferred very heavy structural connection fastener	M48	972kN

* Larger bolts may be required in certain permanent or very heavily loaded structural connections, and intermediate sizes may be required on hydraulic flanges to conform to standard designs

Notes

Paint in the load path of a bolted connection can creep and reduce residual bolt tension. General practice should be to complete bolting before painting. If this is not possible, mask surfaces around bolt and nut heads and on mating surfaces of components to be joined.

If there is no foreseeable chance of a connection requiring replacement during its design life, the fasteners should be over-painted once all tightening and continuity tests are complete

Hydraulic Fittings

As hydraulic fittings are not the same as traditional fastener systems, they are dealt with separately on this sheet.

Preferred thread type:	BSPP (ISO 7)
Preferred seal type:	Metal to metal (cone)

Preferred securing methods:

Fitting Type	Method	Preferred Securing Method	Alternative Securing Method	Torque
Permanent fittings	1	Fully welded or Loctite 278		Use appropriate torque
Diver-removable fittings	2	Loctite 243 in dry	Apply 278 in dry and mate underwater	Use appropriate torque
Onshore maintainable fittings	3	Loctite 243 in dry		Use appropriate torque