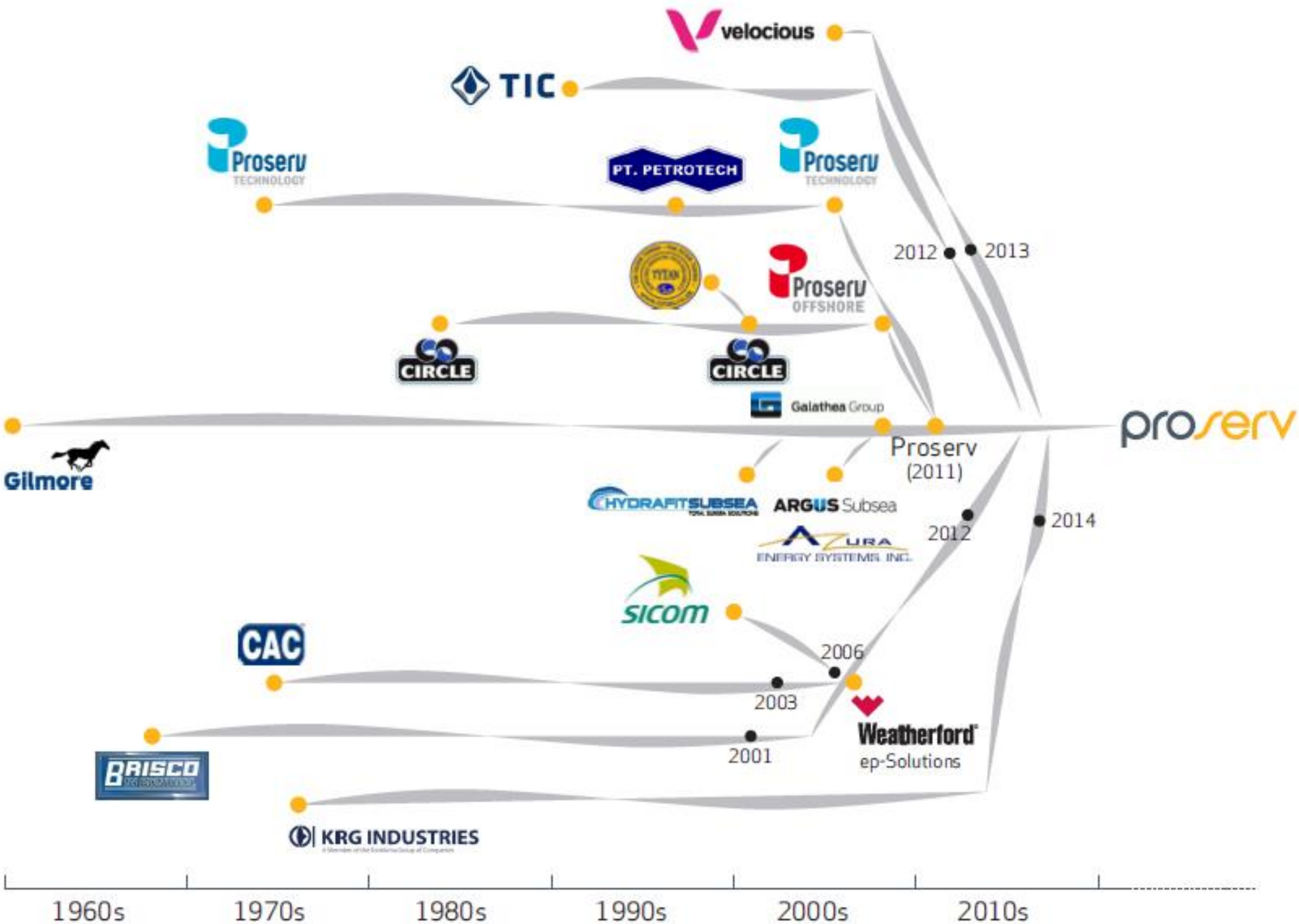
Friction Welding on Offshore Floating Production Systems

To: RINA London Branch 22.10.2015

Dave Gibson - Technical Authority, Friction Welding dave.gibson@Proserv.com

INGENIOUS SIMPLICITY

Proserv's Evolution



What We Do: Life of Field Services

Business Division	What We Offer	Solutions & Services
Drilling Control Systems **(DCS)** 	Products and services focussed **on operational assurance**	• **BOP Services** • **Drilling Control Systems Assurance & Performance** • **After-market & Lifecycle Management**
Production Equipment Systems **(PES)** 	Products and services focussed on **production optimisation**	• **Flow Assurance & Sampling Solutions** • **Production Control & Safety Solutions** • **Asset Performance & Operational Integrity**
Subsea Production Systems **(SPS)** 	Products, services and system design focused on **production enhancement**	• **Subsea Marginal Field Development** • **Subsea Brownfield Extension, Upgrade & Optimisation** • **Obsolescence Management** • **Subsea Life of Field Services & Support**
Marine Technology Services **(MTS)** 	Products and services focused on intervention and remediation to assure **asset integrity**	• **Subsea Infrastructure, Repair & Maintenance** • **Emergency Pipeline Repair** • **Diverless Intervention** • **Wellhead Abandonment & Decommissioning** • **Friction Welding**

Summary

1. The Portable Friction Welding Process
2. Fatigue Strength of Friction Welds
3. Subsea Friction Welding Tooling
4. Subsea applications of Friction Welding
5. Topside friction welding tooling
6. Topside applications of Friction welding
7. Friction Welding in Zoned areas

The Portable Friction Welding Process

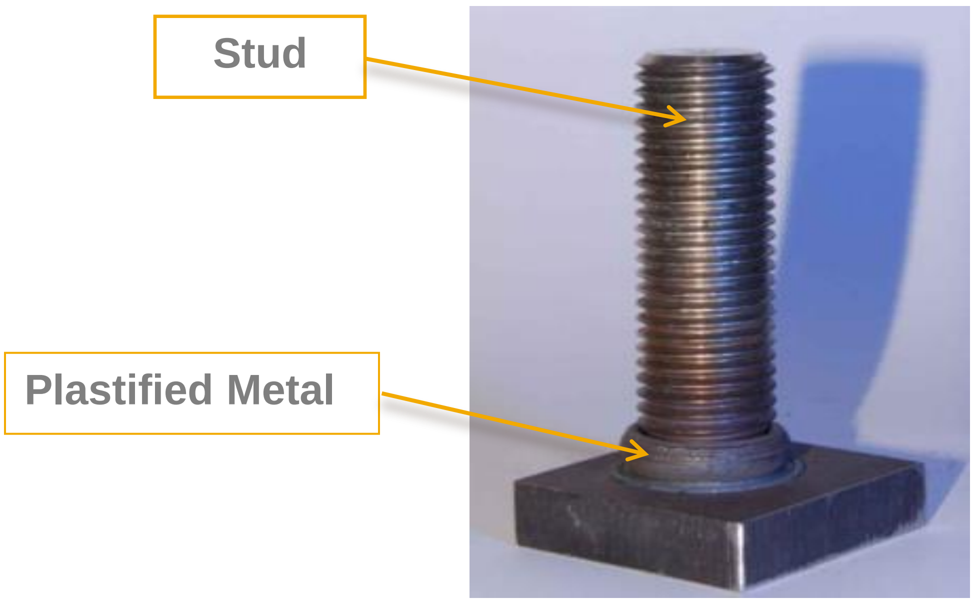
It is a **Solid Phase Process**

1. Rotate the stud at high speed

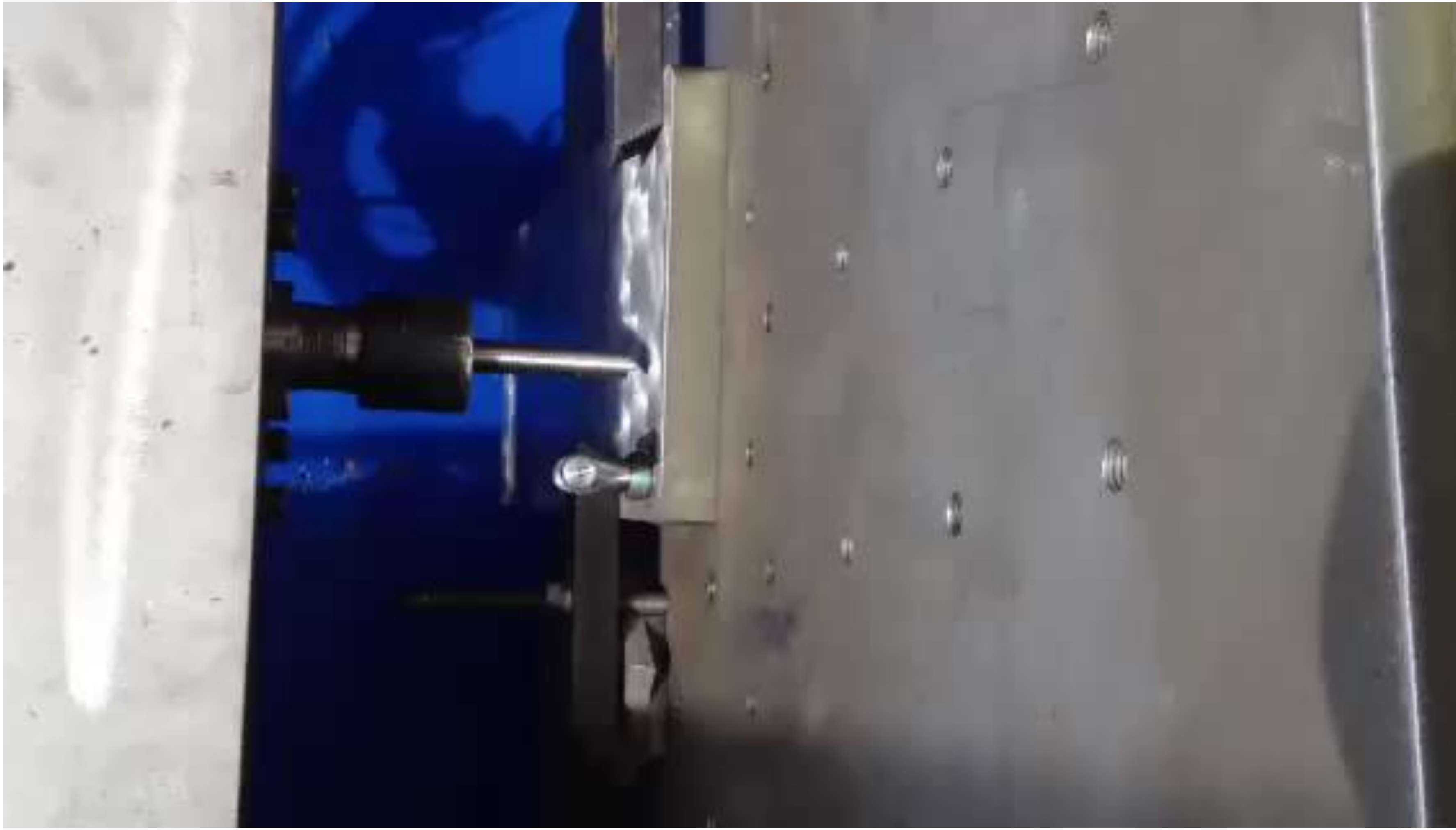
2. Apply pressure forcing the stud onto the substrate.

3. Friction between the stud tip and the substrate causes the metal surfaces to heat and a thin layer of metal to flow plastically under pressure (without melting) to the periphery of the weld, removing impurities from the interface.

4. The rotation is stopped and the pressure maintained for a few seconds to produce a solid phase forged weld with a fine grain structure



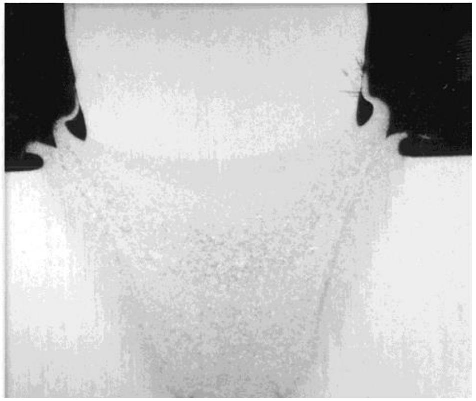
The friction welding process



Friction Welding Configurations

Stud Weld

Tripartite Weld



Taper Plug Weld

Nipple Weld

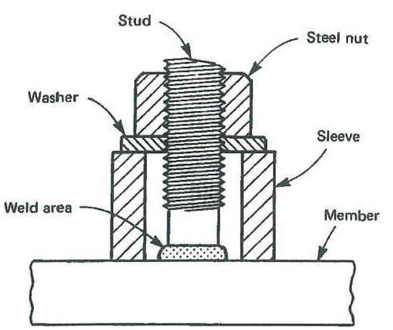
Friction Welding process characteristics

- Solid phase process with no liquid weld pool or electric arc
- Hydrogen is not evolved or absorbed in significant concentrations during welding so no requirement for preheating
- Residual stresses at the weld are compressive giving very good fatigue strength
- No slag inclusions or porosity
- Welding can often be done without removing coatings
- Used for welding underwater or in potentially explosive atmospheres with a shroud and water sprays
- Can be applied where avoiding damage to the coating on the back of the base material is critical
- No mixing of stud and base material so dissimilar metals can be joined readily
- Suitable for use ROVs underwater on large flat surfaces where clamps cannot be used.
- Can be used on live pipes

The mechanical properties of friction stud welds

Tensile strength exceeds the specified minimum UTS for the stud

QW-466.5 TORQUE TESTING ARRANGEMENT FOR STUD WELDS

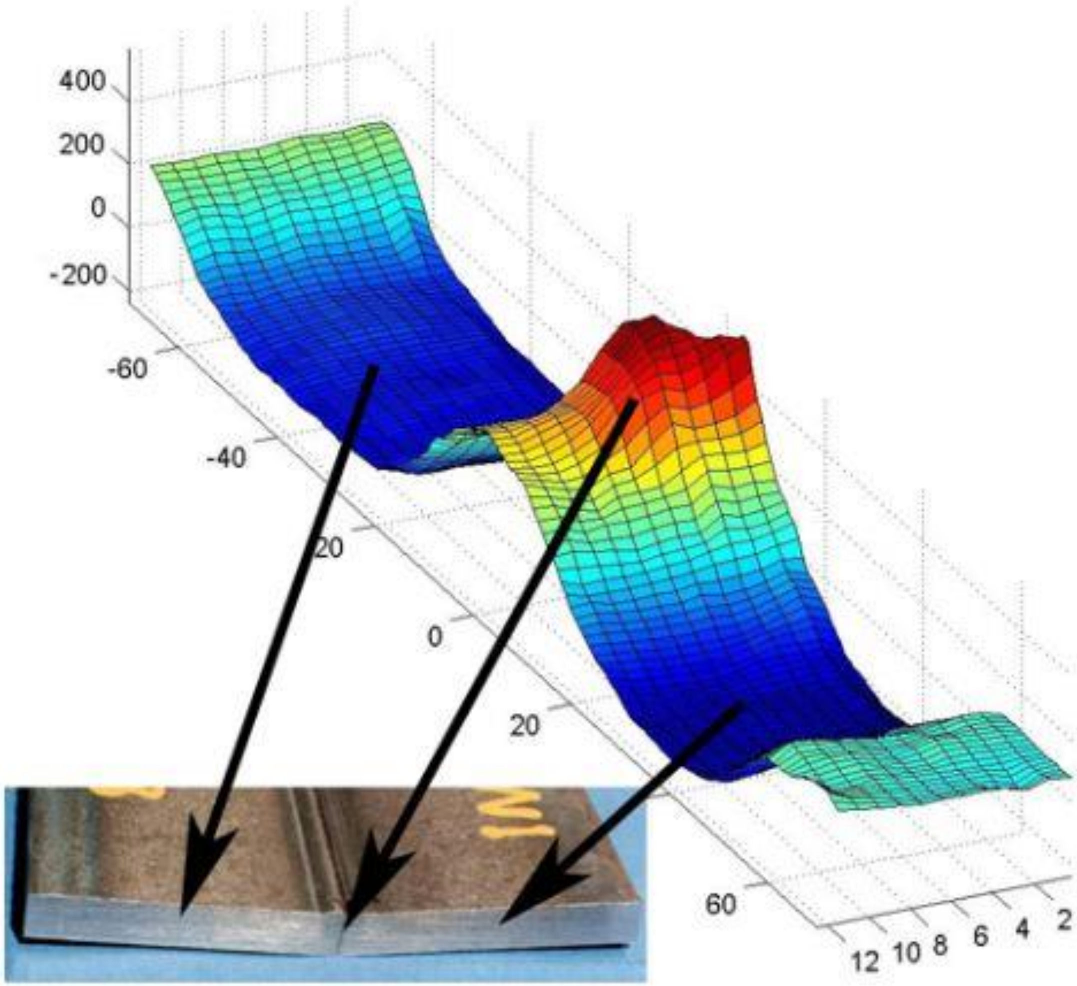


GENERAL NOTES:
(a) Dimensions are appropriate to the size of the stud.
(b) Threads of the stud shall be clean and free of lubricant other than residual cutting oil.

Bend test to ASME IX or AWS D 1.1

Fatigue Strength of Friction Welds

Residual Stress in Fusion Welds (Electric Arc Welds)



.

Typical residual stress pattern for a fusion butt weld made with arc welding

Residual Stress in Friction Welds
(TWI Report 485/1995) Ref. 1

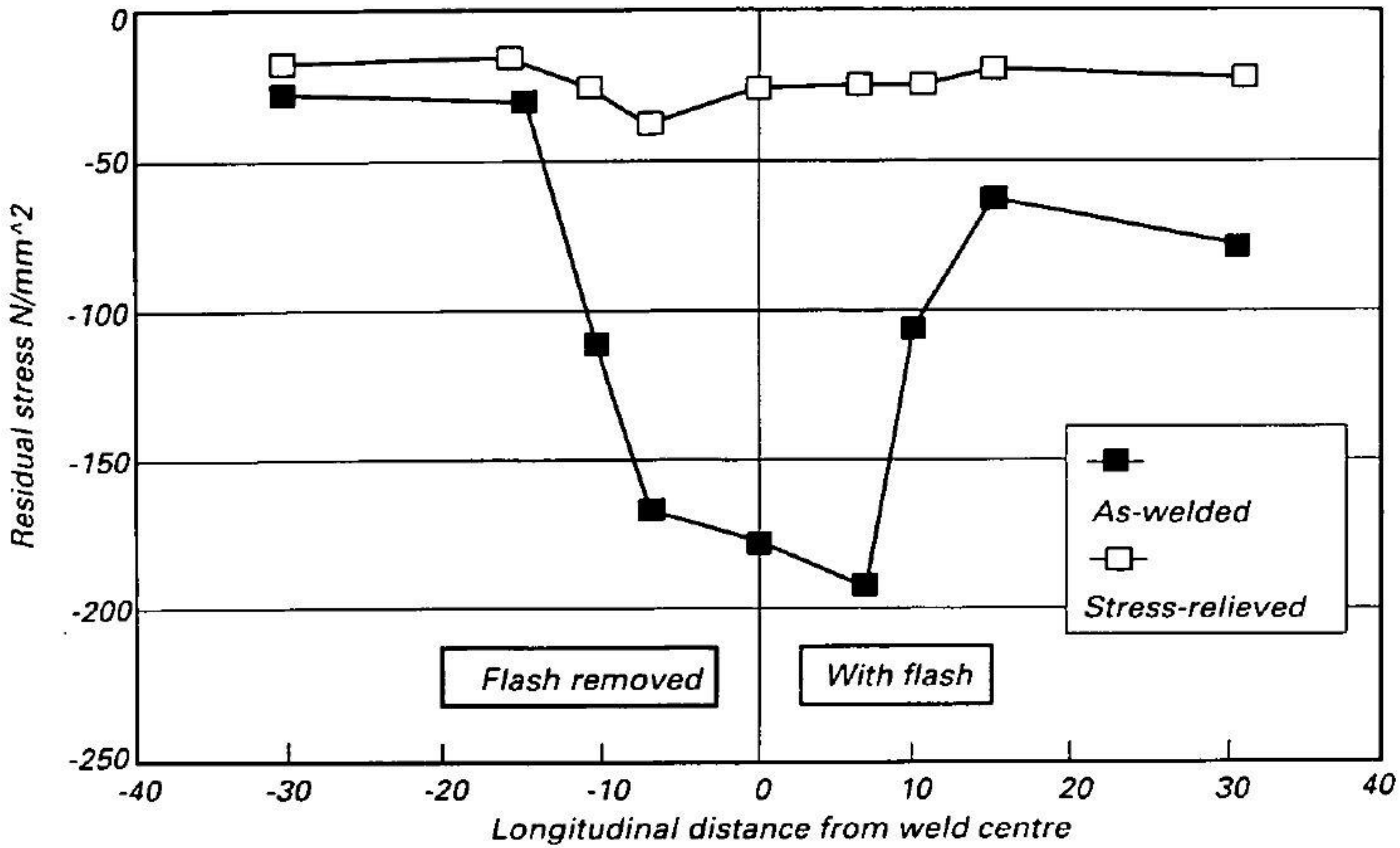


Fig.5 Residual stress measurements in the axial direction (i.e. perpendicular to the weld) obtained from specimens 77210-23 and 77210-24 representing the stress relieved and as-welded conditions, respectively.

Fatigue Strength of Friction Welds
(TWI Report 485/1995) Ref. 1

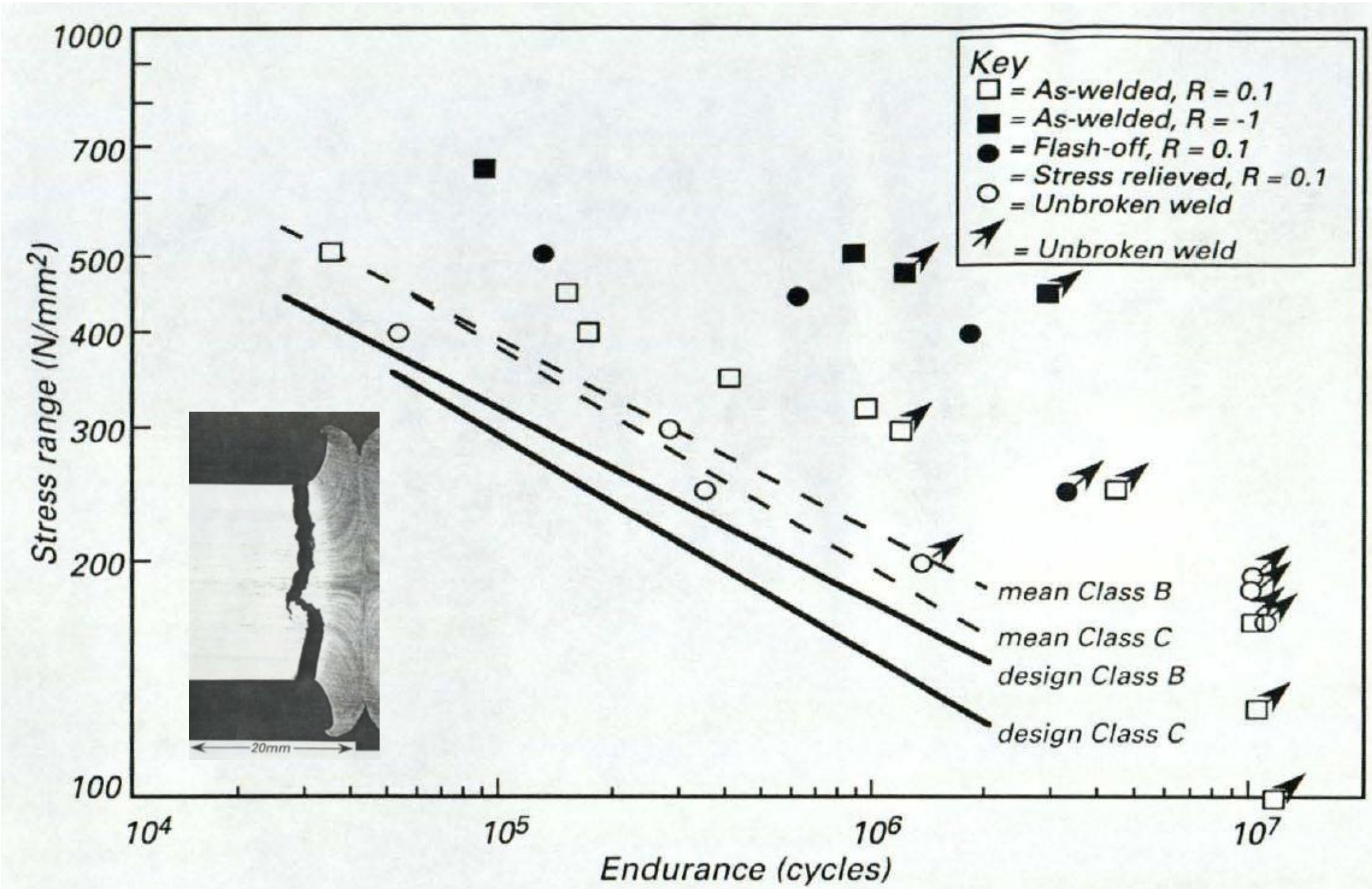


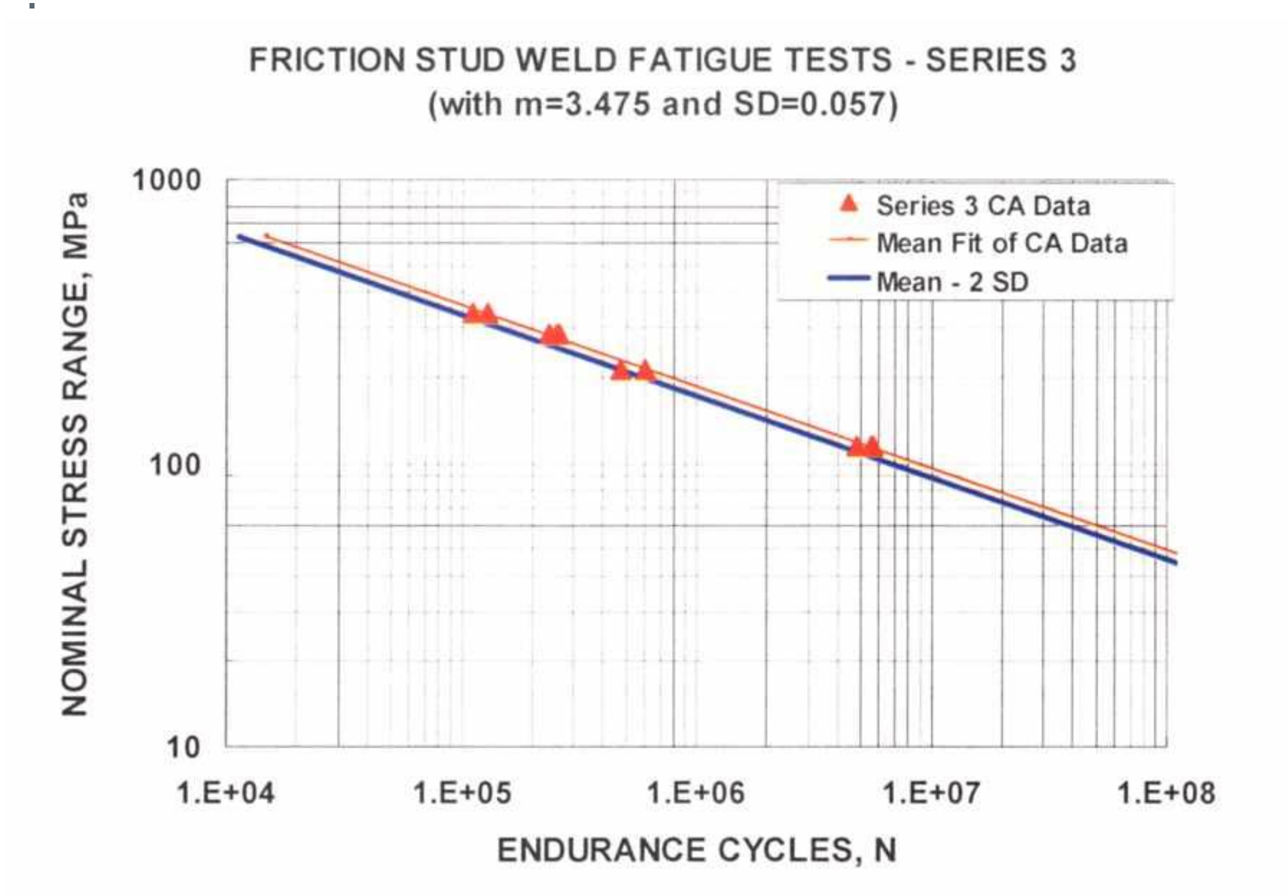
Fig.7 Fatigue test results obtained from friction welded rod-to-rod connections.

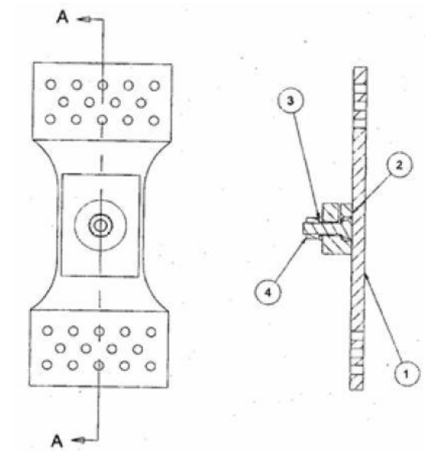
Conclusions from TWI Report 485/195 (Ref. 1)

- Fatigue strength of the friction welds tested at R=0.1 was superior to Class B, BS5400: Part 10
- The high fatigue strength of friction welds appears to be due to beneficial residual stress distribution at the surface adjacent to the failure site.
- Thermal stress relief reduced fatigue strength as a result of removing the beneficial compressive residual stress. Nevertheless the fatigue strength of the stress relieved specimens was still high roughly equivalent to Class C in BS 5400 Part 10.

Fatigue tests on Subsea Friction welds – Chevron Genesis Riser Guide Support Replacement

.

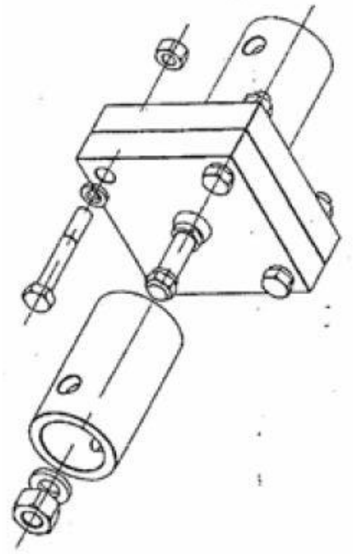


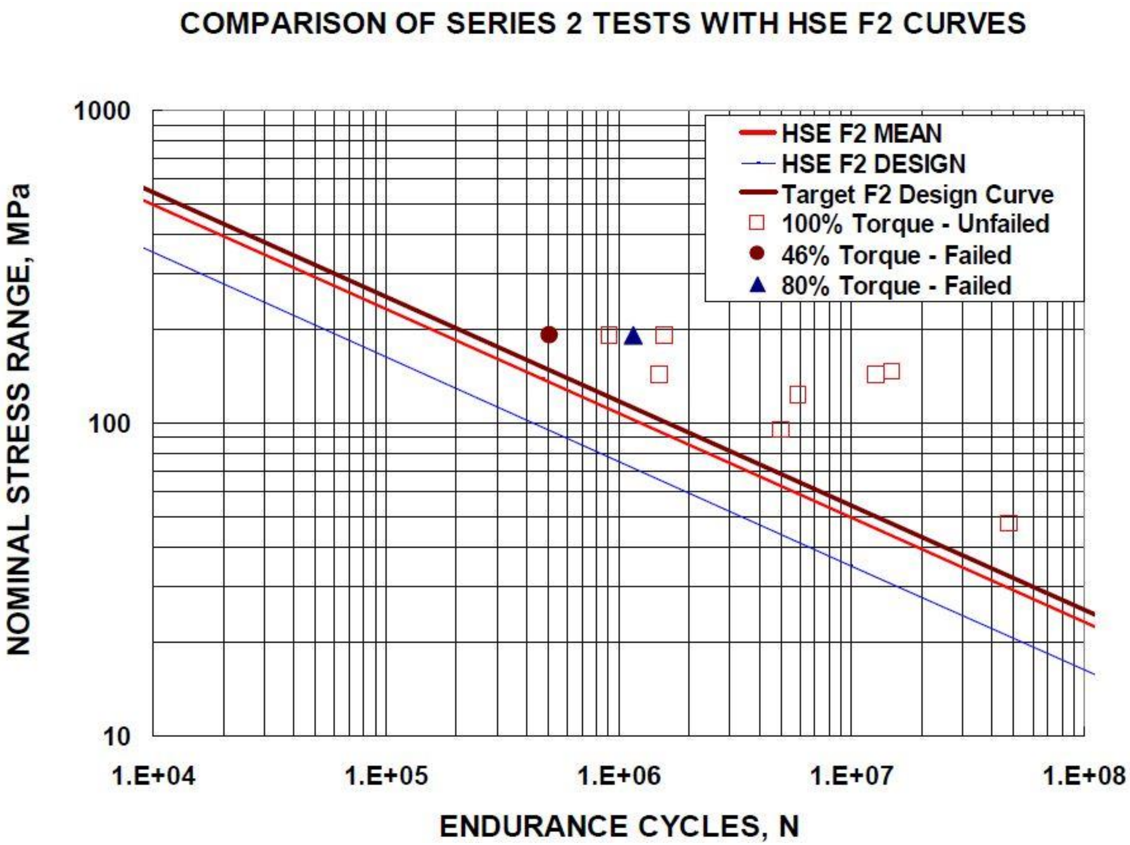


C1 Curve from underwater fruiction stud welds. Fatigue tests representing the presence of a friction weld on the moon pool hull plate as it sustains global bending without the live load applied through the stud

Fatigue tests on Subsea Friction welds – Chevron Genesis Riser Guide Support Replacement

.

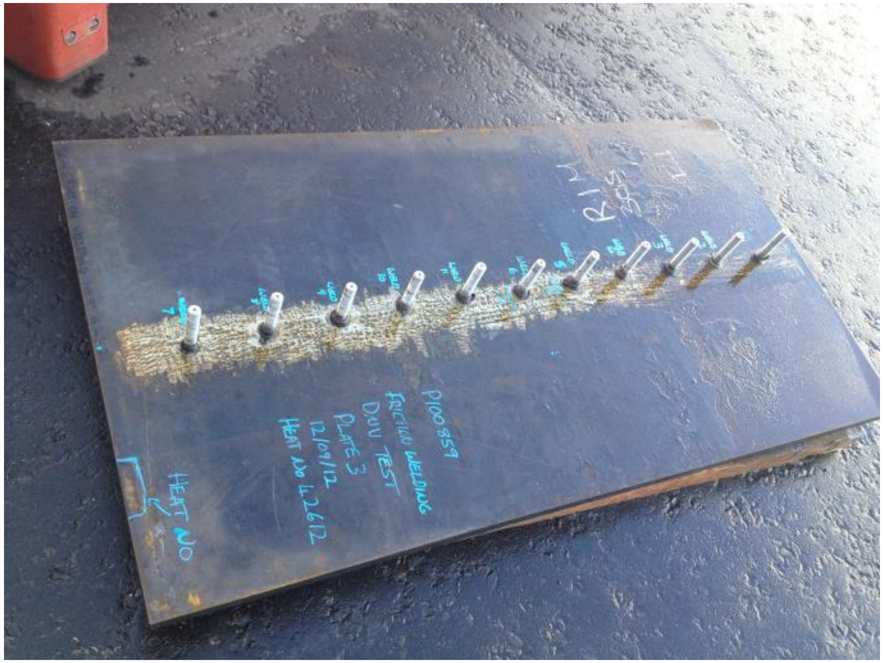




Fatigue test data on subsea 19mm friction stud welds preloaded with a 100% torque of 170 Nm (Series 2 in Ref.3) subject to axial load.

Fatigue Tests for Wind Farm Piles by DNV

Bend tests on M16 underwater stud welds



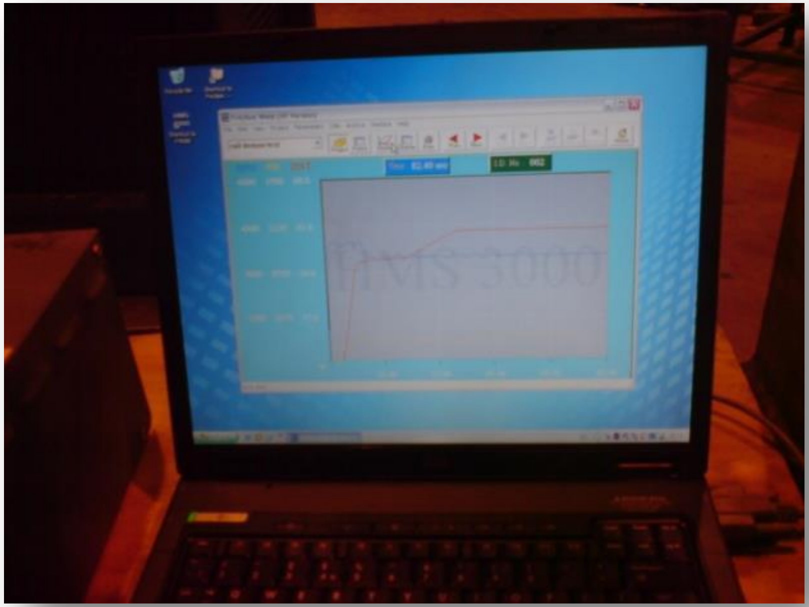
One of three test plates stud welded for fatigue testing by DNV

- The data from these tests gave a C1 curve

Subsea Friction Welding Tooling

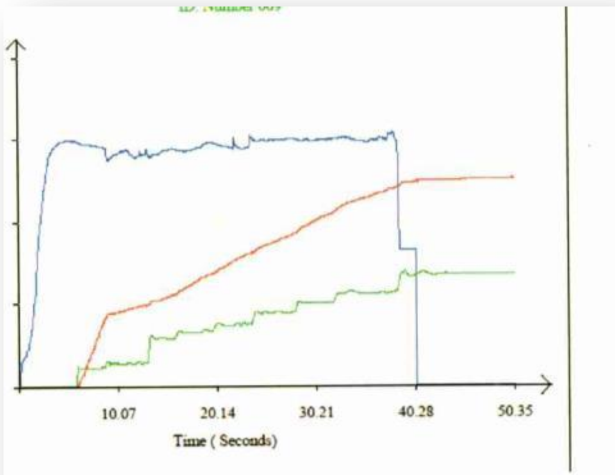
Hydraulic Friction Welding Systems

The HMS 3000 Hydraulically powered & computer controlled system



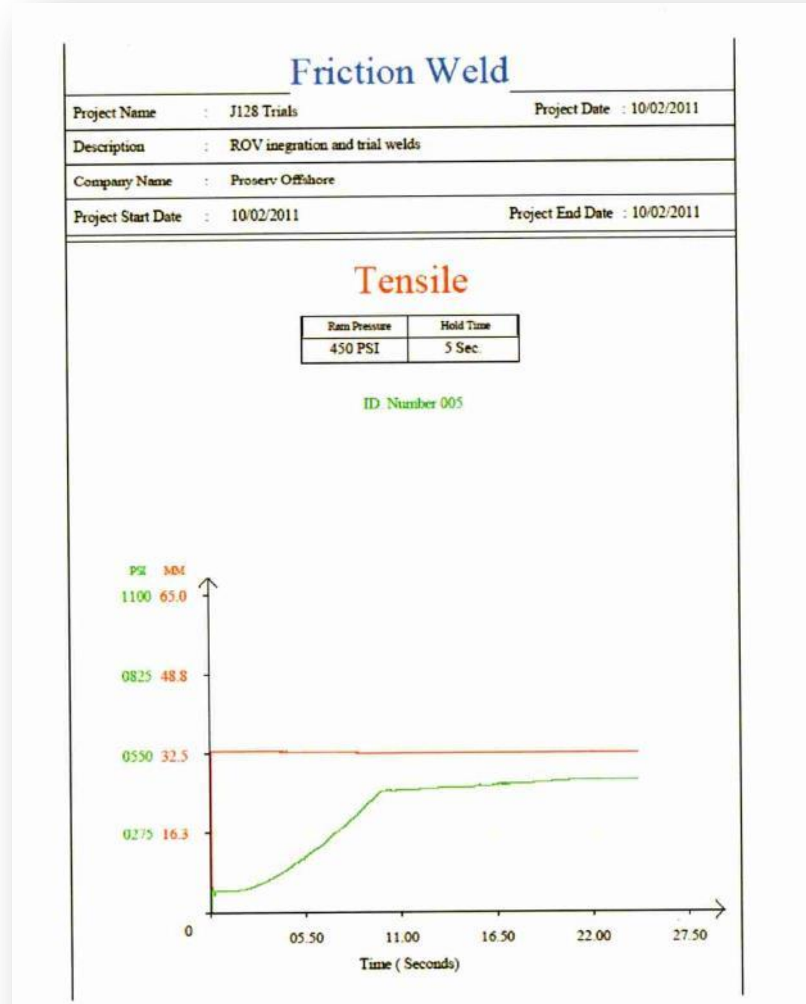
Capable of welding studs up to 25 mm diameter to a water depth of 1000m or more

Hydraulic Friction Welding System – Weld Data.



Weld graph #9

- Typical data from the friction welding control system: Rotational speed, ram pressure and "Burn-off". The tool can also perform a tensile test if required.



Friction Weld

Project Name	: J128 Trials	Project Date	: 10/02/2011
Description	: ROV inegration and trial welds		
Company Name	: Proserv Offshore		
Project Start Date	: 10/02/2011	Project End Date	: 10/02/2011

Tensile

Ram Pressure	Hold Time
450 PSI	5 Sec

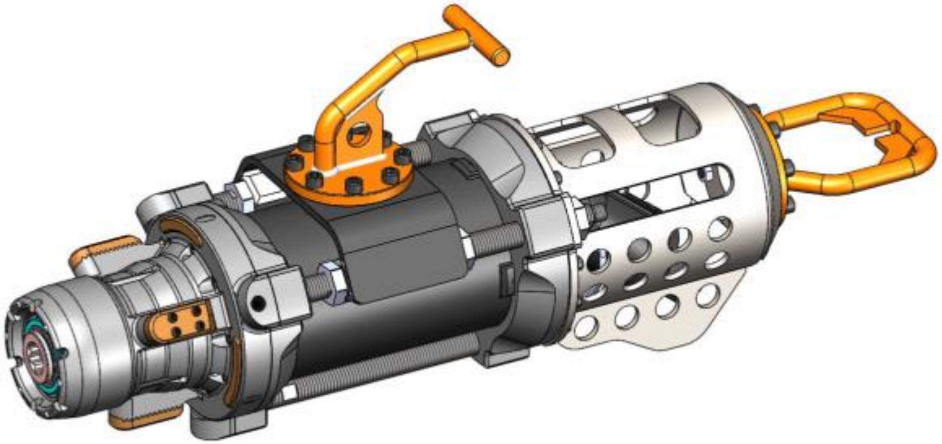
ID Number 005

Tensile graph #5 (Aft)

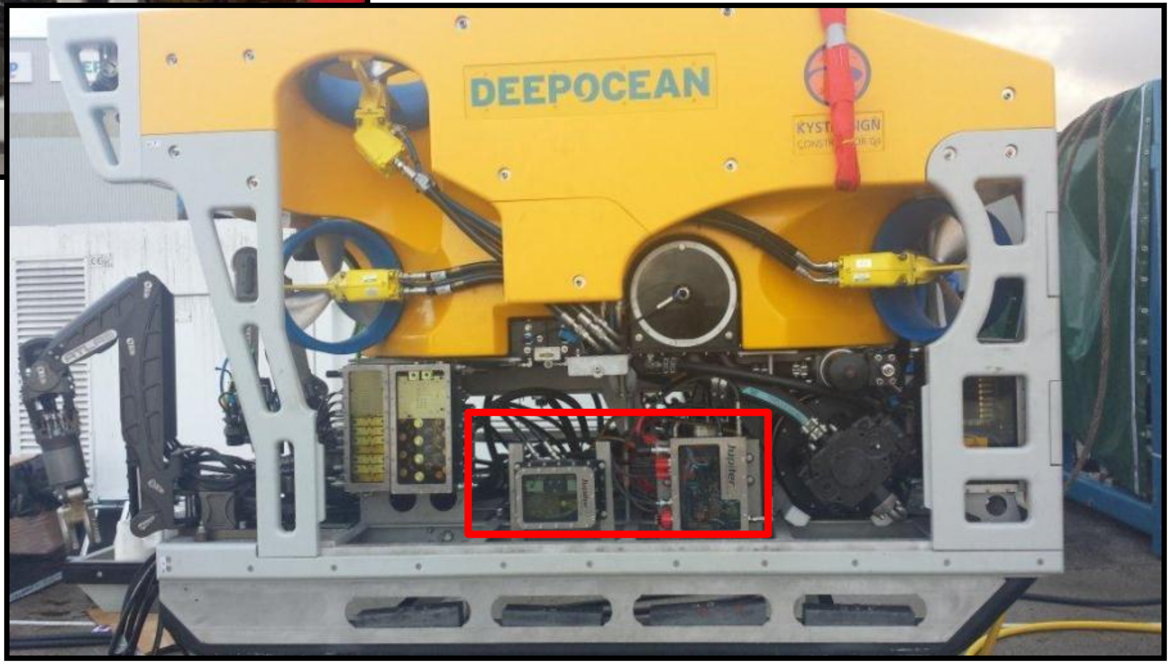
Technology Developments – Subsea Stud Changer

- Diver operation of the weld head with a magnetic clamp

- ROV deployed weld head assembly with a remotely operated subsea stud changer



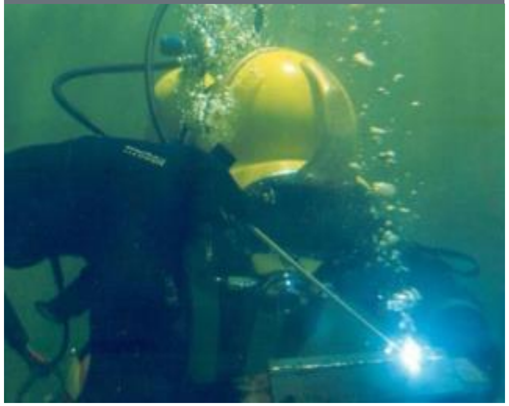
Hydraulic System Integrated onto an ROV



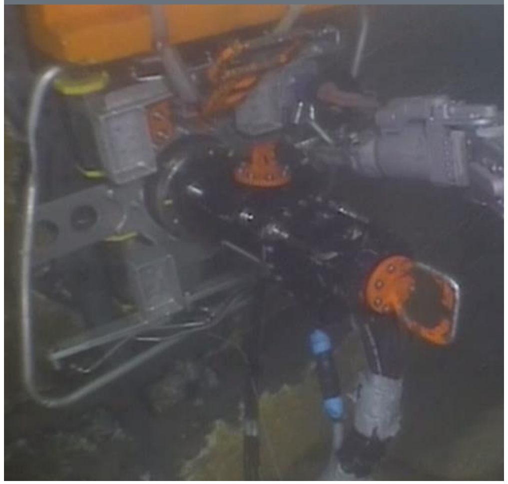
Subsea Applications of Friction Welding on FPS

Options for a Hull Cathodic Protection Retrofit

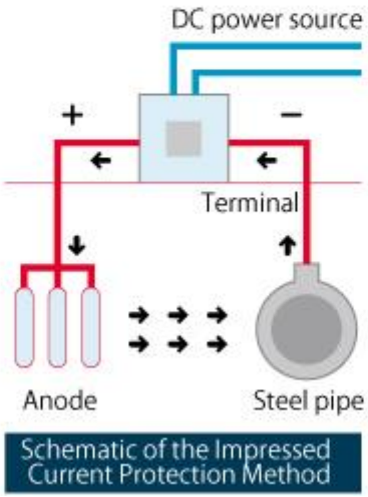
Subsea
Wet Welding



Subsea
Friction Welding

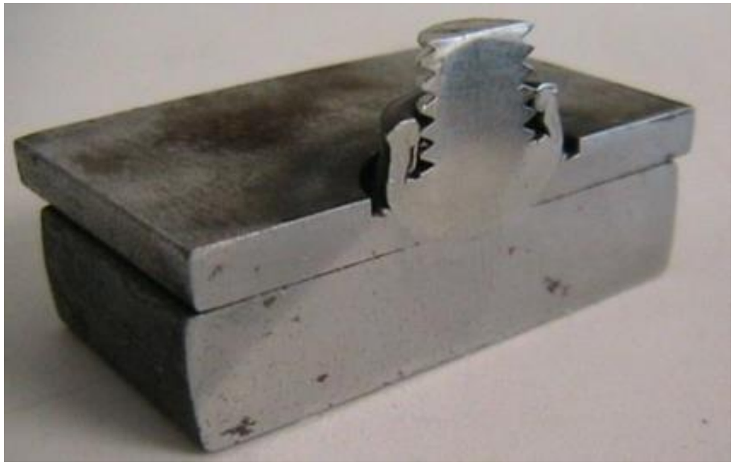


Subsea
Impressed Current Cathodic Protection (ICCP)



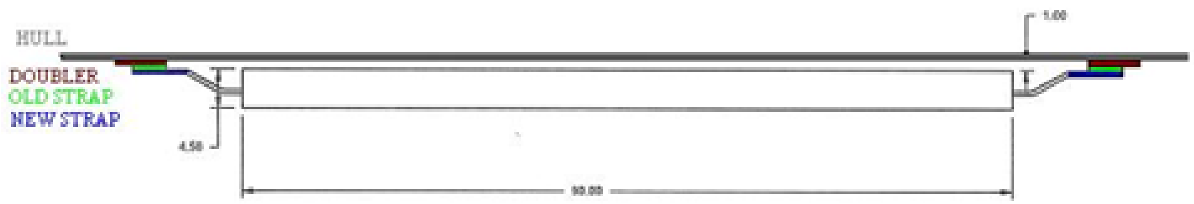
Anode Attachment to an FPS Hull with an ROV

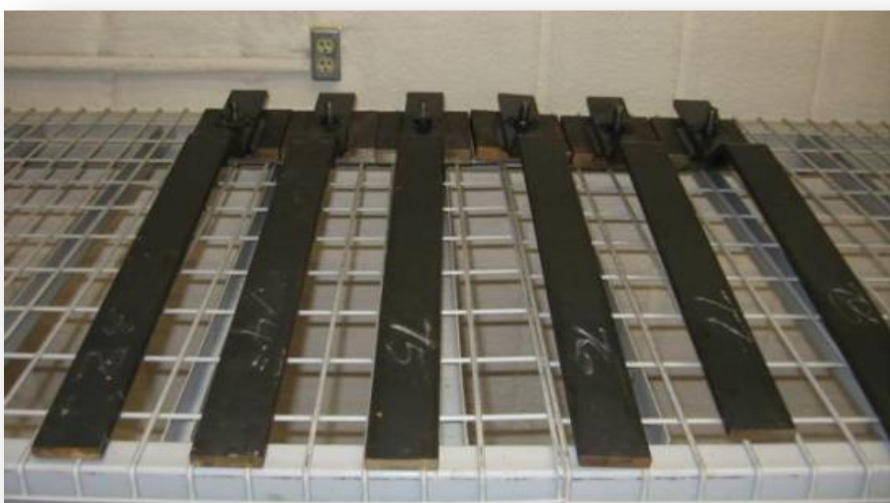
Tripartite friction weld



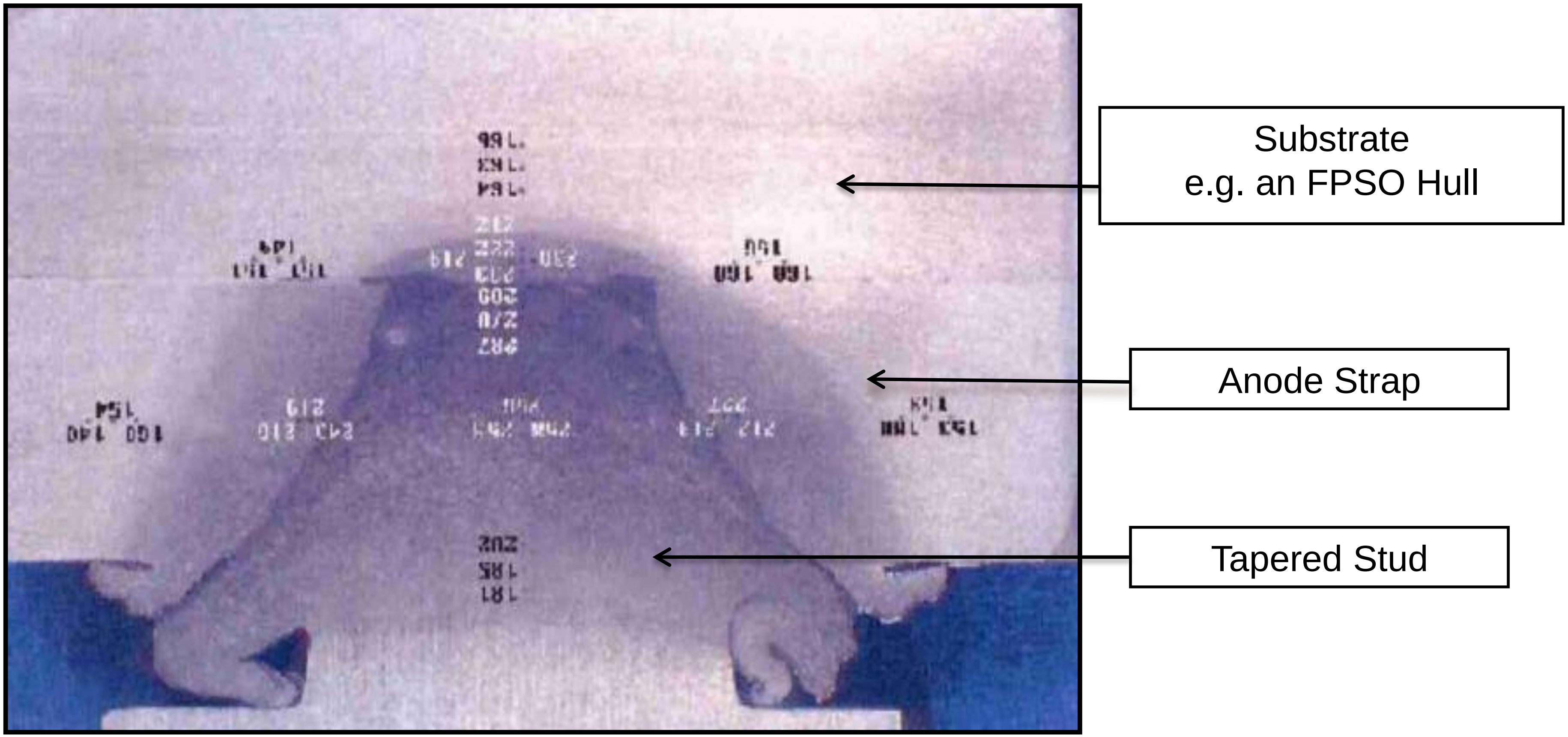
Proserv friction welded 220 large 450 pound anodes underwater to the hull of the BP Thunderhorse FPSO in the GOM from an ROV, 2011 to 2013

Fatigue test of Tripartite Friction Welds for Anode Attachment

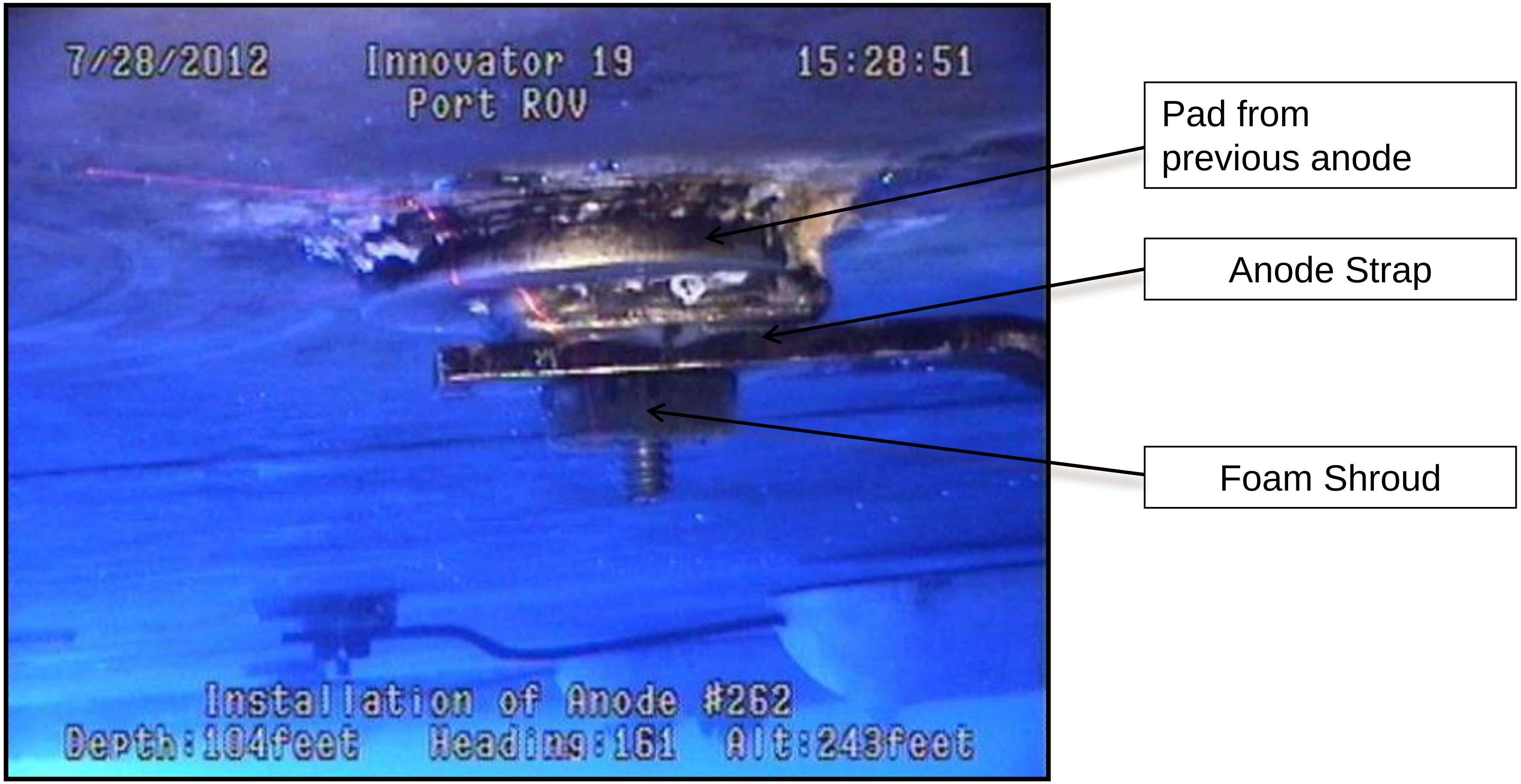




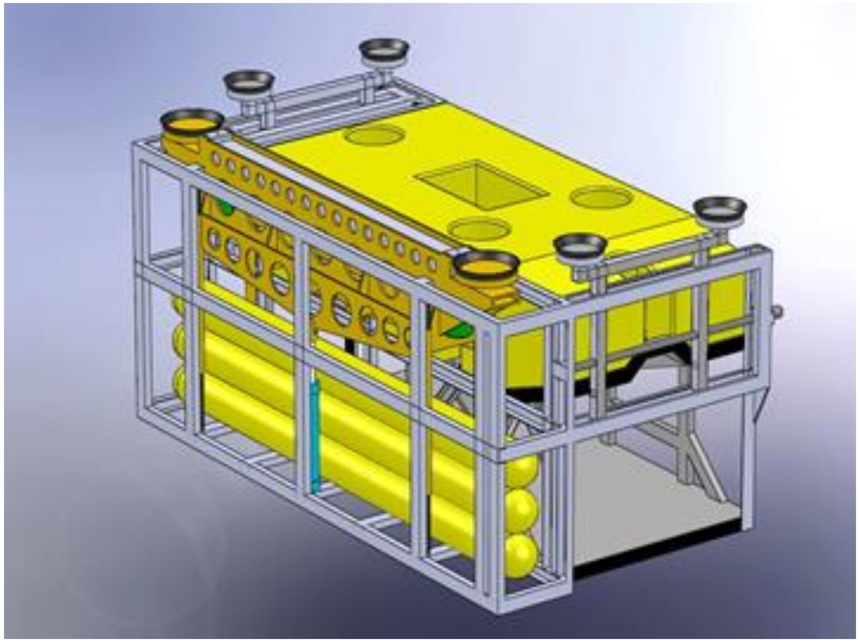
Tripartite friction weld configuration used for welding anodes to the FPS



Tripartite friction welds done with an ROV for anode replacement on a FPS



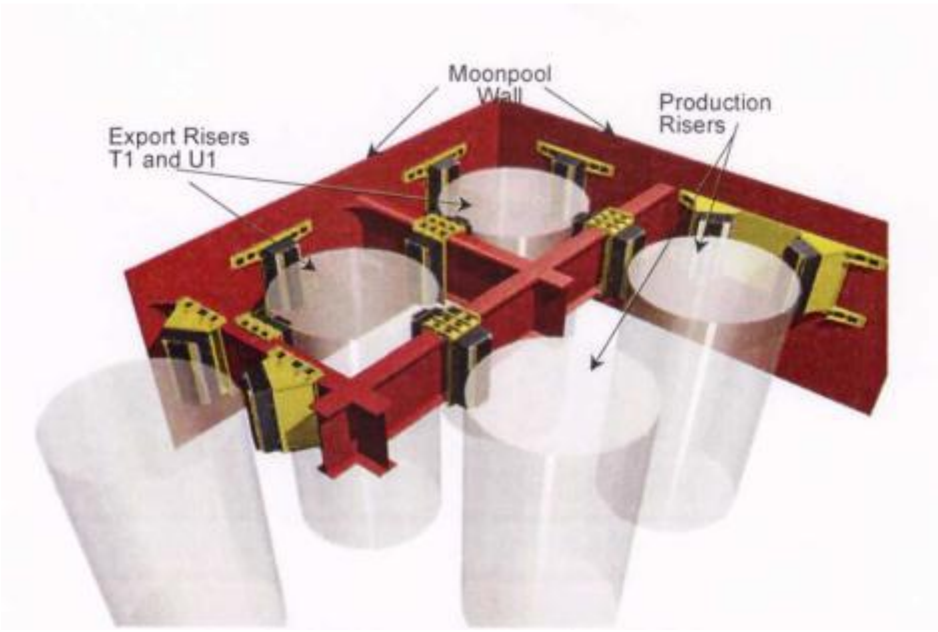
Hull Anode Attachment Tooling



Final inspection of anodes on FPS hull

Structural Securing of Risers

Subsea friction stud welding has been used for retrofitting clamps or attachments to offshore structures.



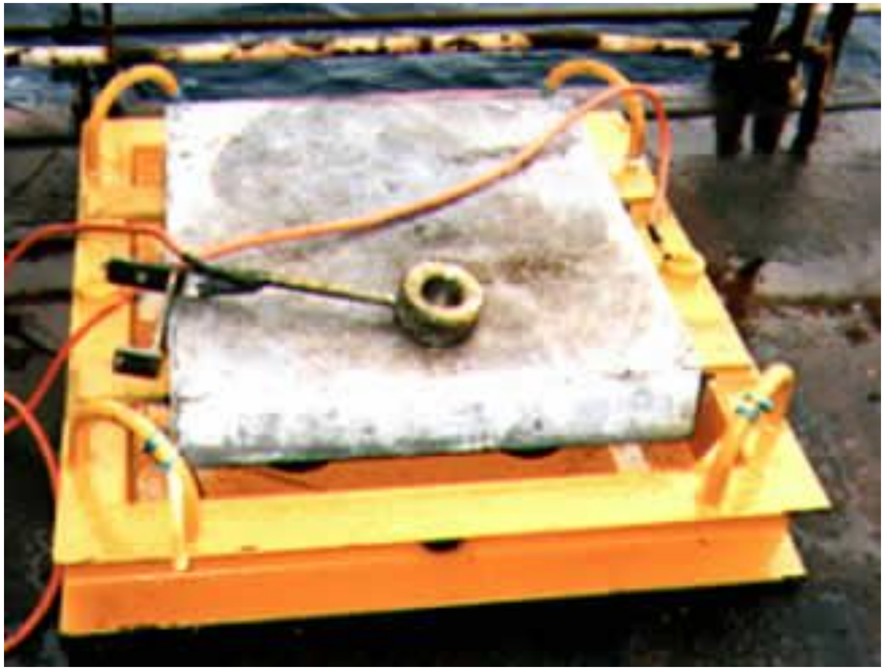
Welding 20mm studs in the moon pool of Chevron's Genesis platform for replacing riser bumpers.

Stud and Cable Attachment to Subsea Structures

Anode Sled Connection to Subsea Assets

West of Shetland – using an ROV at 395 m (BP Schiehallion) . The studs and anode continuity tails were welded directly to 36inch subsea riser base piles using "Tri-partite" welds. This gives a welded connection between the anode continuity tail and the pipe minimising the electrical resistance of the connection.

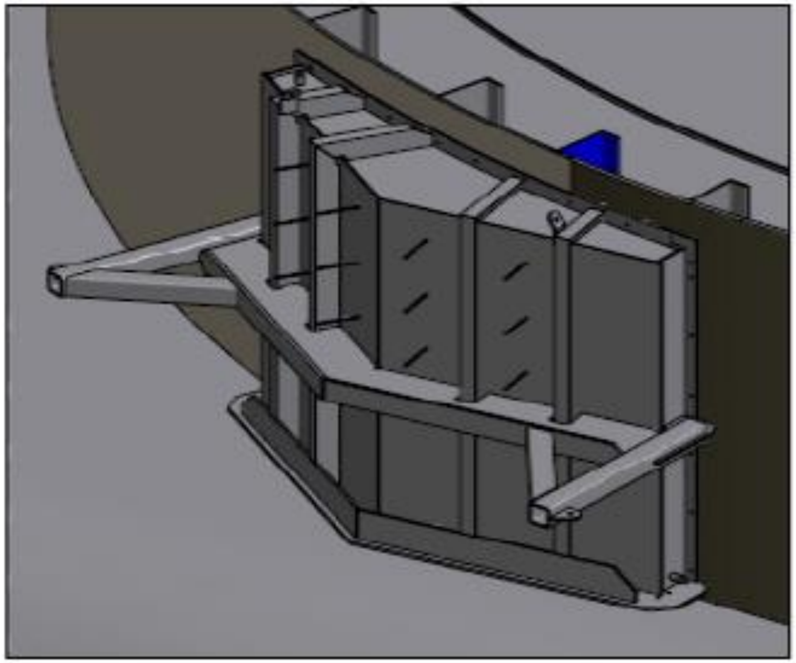
Schematic of ROV with Stud Welding tool



Anode skid with the continuity tail ready for Tri-partite friction stud welding

Crack Repairs on FPSO & FPS Hulls Using Cofferdams

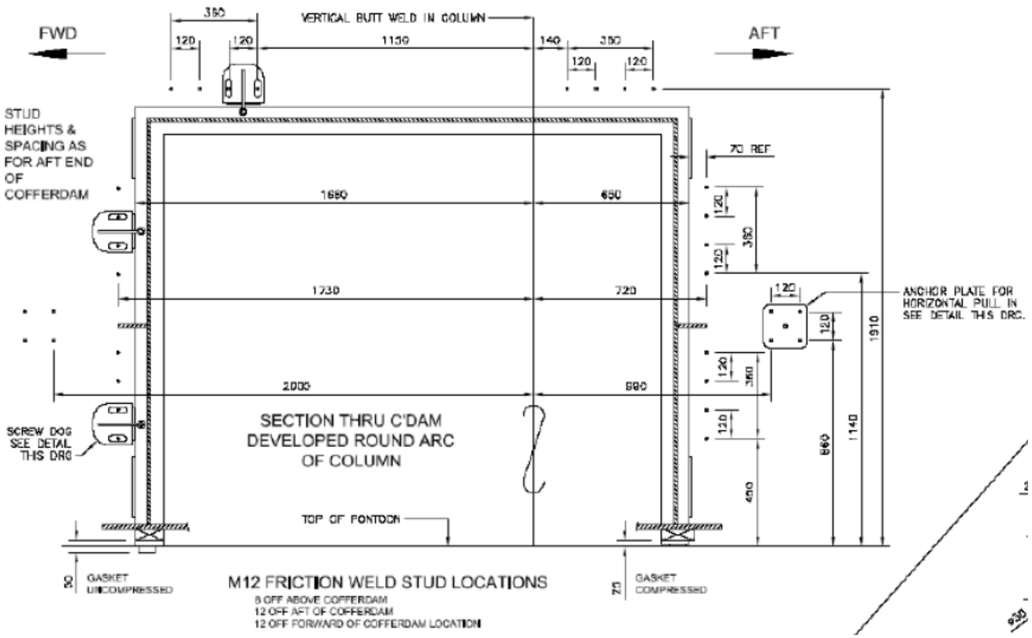
Lowering the cofferdam

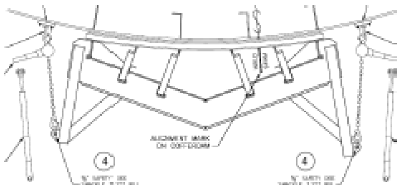


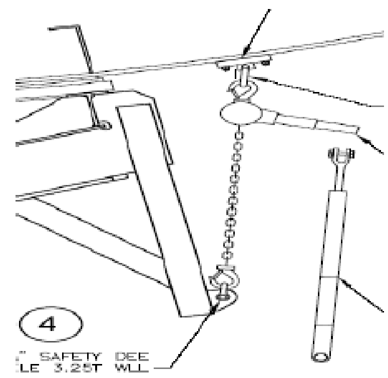
The cofferdam in position over a crack in a weld between a column and a pontoon on an FPS

Using Friction Stud Welding to attach a cofferdam to the hull of an FPS so that a crack can be repaired using dry welding with preheat.

Crack Repairs on FPSO & FPS Hulls Using Cofferdams







Subsea friction stud weld locations for the cofferdam attachment to the FPS hull

A jig for locating the friction stud welding tool

An anchor plate with four friction stud welds

Crack Repairs on FPSO & FPS Hulls Using Cofferdams

Access window cut in the FPS hull after the cofferdam was attached

The cracked weld after repair and heat treated

The access window closed and re-welded

Crack Repairs on FPSO & FPS Hulls Using Cofferdams

Jig for welding studs for Cofferdam attachment

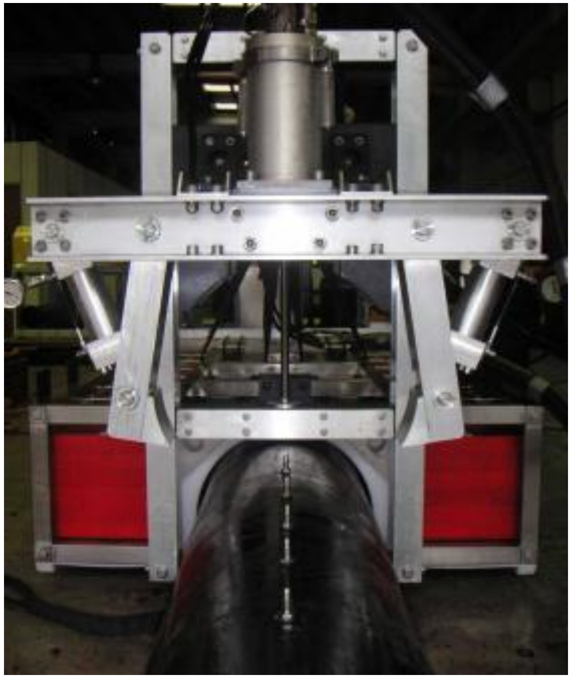
R1004 Friction welding tool in a magnet clamp

150mm long M12 Stud Weld

Repair to a water below water line crack in an FPSO using a cofferdam attached with strongbacks held on the hull by friction stud welds done by rope access technicians or divers (Maersk Gryphon FPSO)

Anode Attachment on Live Subsea Pipelines

China 2005 – Water depth 113 to 120 m.s.w. M12 316L Stainless steel studs welded at 64 locations on the pipeline. The studs were welded to the top of the pipeline using an ROV and the anodes were then installed on the studs. Client CNOOC.



Testing the HMS3000 stud welding system in the ROV tool skid

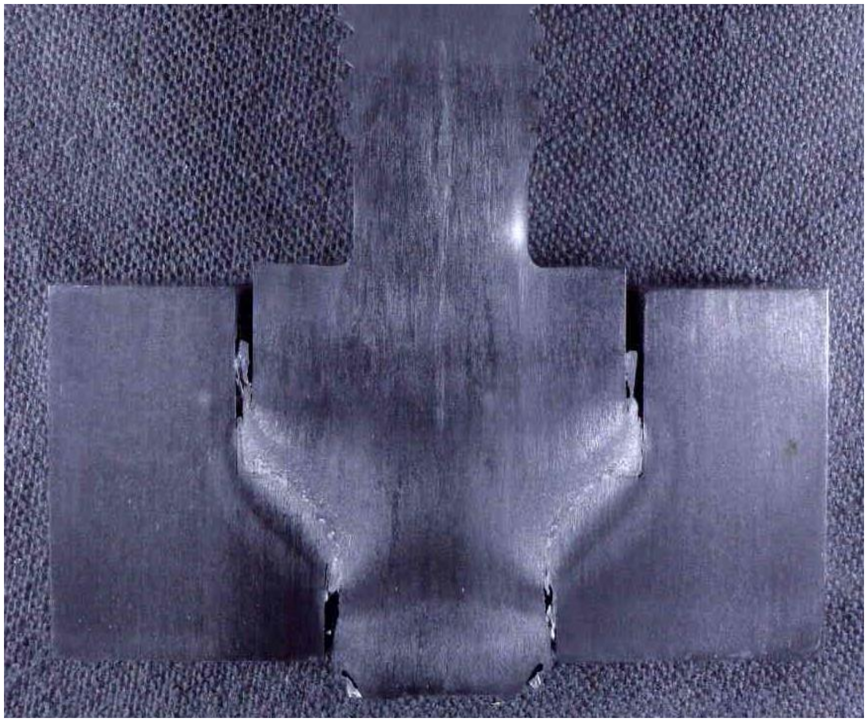
The ROV with the stud welding tool skid

Friction stud on live subsea pipelines from an ROV

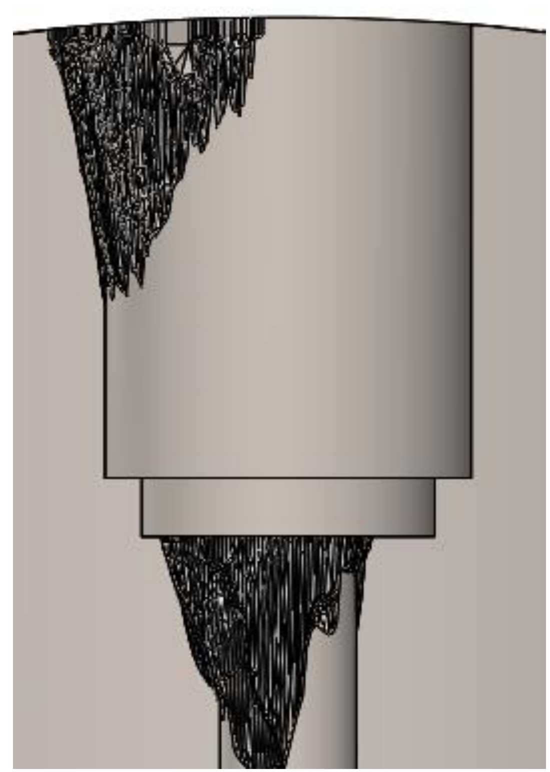
- A 316L stainless steel stud friction welded though an epoxy coating to a subsea pipeline

- Anode installation on the pipe following friction stud welding

Underwater Friction Plug Welding for a valve repair



Friction plug weld on 40mm thick S32760 Super Duplex Stainless Steel



Hole eroded by cavitation machined for friction plug weld

Topside Friction Welding Tooling

Pneumatic Friction Welding Systems

Pneumatic Friction Welding System for use Topside
(shown here with a magnet clamp)

Friction Welding Underwater and in Areas where Hot Work is Not Permitted

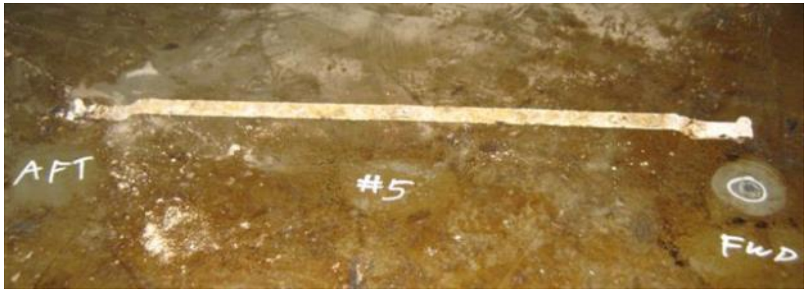
The stud weld is encased within a foam and metal shroud.
In addition, for welding in zoned areas a water spray can also be applied during the welding and spark arrestors are fitted to the air exhaust .

Stud welding in zoned areas

Topside Applications of Friction Welding offshore

Anode Attachment in Oil or Ballast Tanks on FPSOs (Zone 1)

Proserv’s R1400 pneumatic tool was used for retrofitting 160 anodes in a oil storage tank on the Terra Nova FPSO in Zone 1.



Anodes after 12 years service in an FPSO oil storage tank.

Friction Welding Explosive Atmosphere Test

After the weld has been completed the gas mixture of 14% Acetylene and air is detonated to verify that the gas was explosive.

Friction Welding on Live Pipelines for corrosion sensor attachment

Firewall replacement offshore

The R1004 Friction Welding tool in a magnet clamp.

A stud for attaching a fire wall friction welded to the accommodation module on the platform

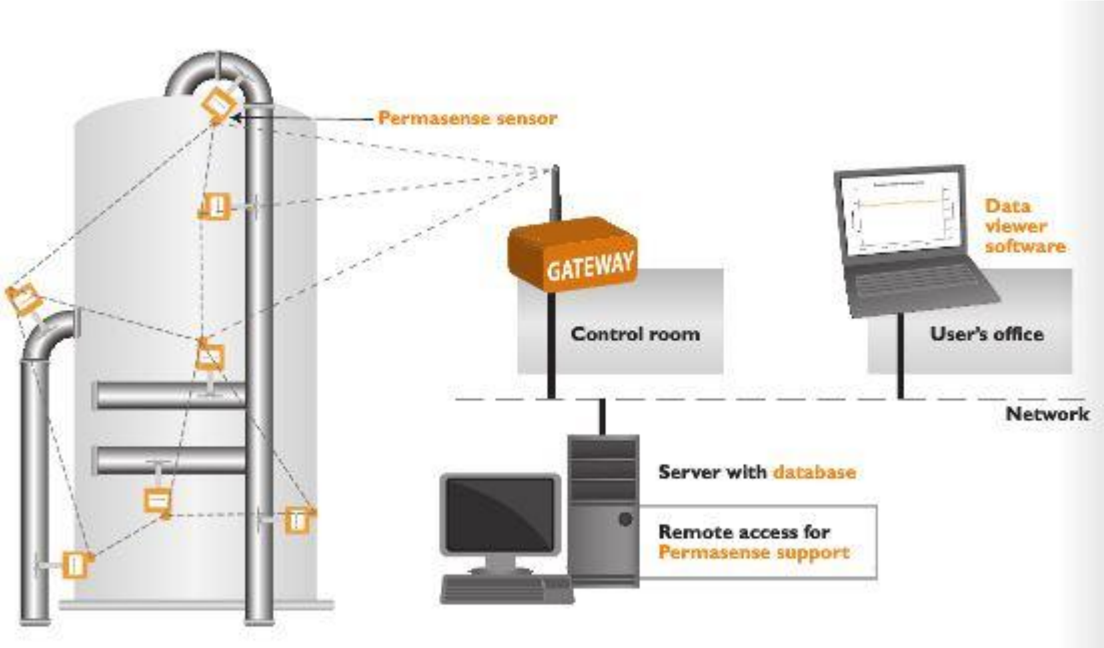
The accommodation remained fully occupied during the project with no fire risk on the inside due to welding

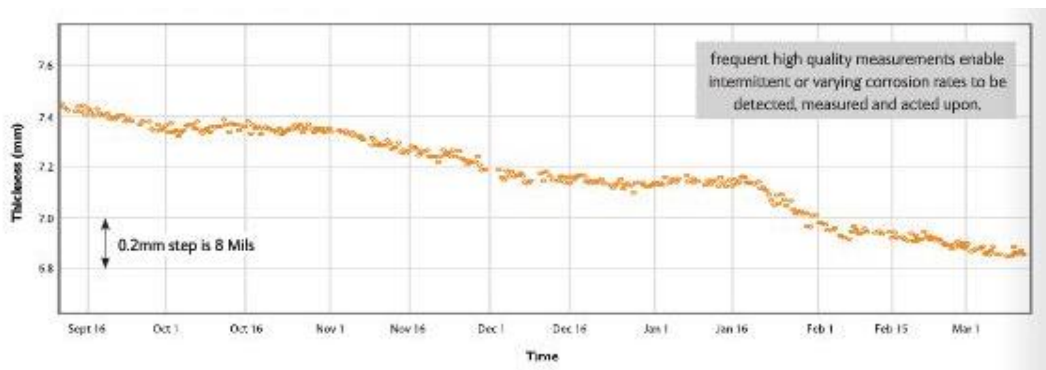
Friction Welding onto live pipes

Friction Welding on Live Pipelines for corrosion sensor attachment

proserv

Continuous corrosion monitoring system installation





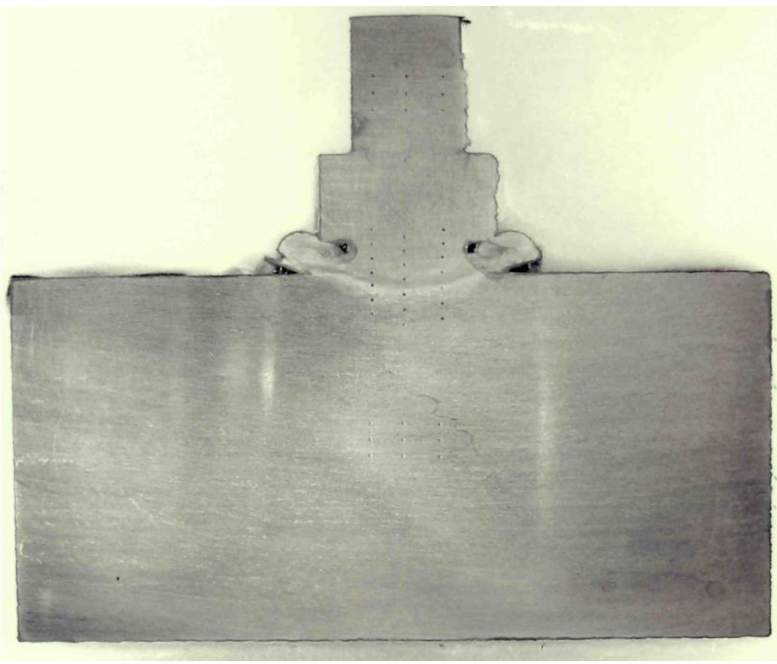
Continuous corrosion monitoring using wireless waveguide based ultrasonic thickness measuring sensors.

Friction stud welding on live pipes in zone 1 areas for sensor corrosion sensor attachment

Friction welding procedures were qualified using the explosive atmosphere test with the explosive gas mixture inside the pipe as well as surrounding the weld for pipes carrying hydrocarbons.

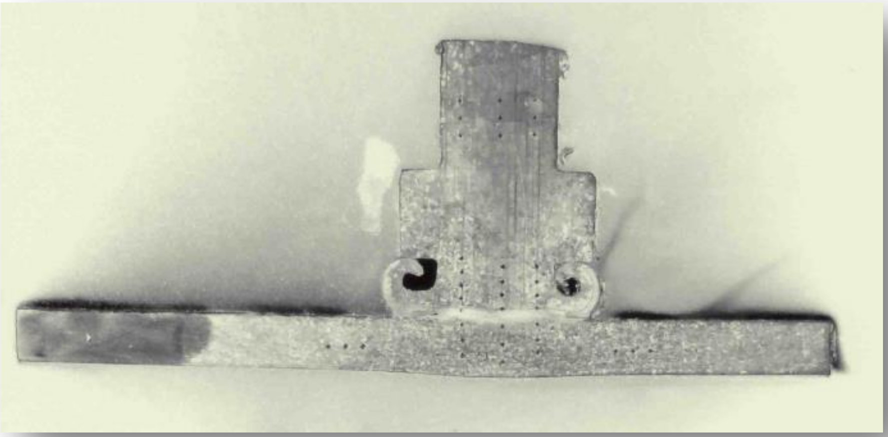
Friction Stud Welding on the wall 25.4 mm wall 2205 pipe.

A Welding Procedure Qualification test will be done in accordance with ASME IX for this project on the 2205 Duplex Stainless Steel pipe and witnessed by DNV. Preliminary tests gave acceptable bend and macro results. Maximum hardness was 279 HV10, Ferrite volume 56% and microstructures acceptable to DNV OS-F101:2010



2205 M8 Studs Friction Welding to 2205 Schedule 180 pipe

M8 Friction stud welds on SMO254 pipe



Explosive atmosphere test and macro for M8 friction stud welds on SMO 254 Super Austenitic Stainless Steel. The pipe is 3mm wall thickness and contains a water glycol mixture.

Max. Hardness 246 Hv10. Microstructure: Bond Zone – Ultrafine grained austenite. HAZs –Fine grained and equiaxed austenite with ultrafine grained austenite at the grain boundaries (see report)

References

1. Manteghi S, "Some fatigue tests on friction welded steel bars", TWI Report 485/1994, July 1994

2. Gibson D, Paculba N and Grey I, "Friction Stud Welding Underwater in the Offshore Oil and Gas Industry", State of the Art, Science and Reliability of Underwater Welding and Inspection Technology – Workshop – Houston November 2010, ABS

3. Hsu TM, Herman A, Buitrage J and McKeighan PC, "Fatigue Performance of Friction Welded Studs", OMAE 2005 – 67209

4. Jeevanandam Shanmugam and Gibson D, "A novel approach to installing sacrificial anodes to protect glass flake lined steel large diameter seawater pipeline systems." International Corrosion Congress, Perth, Australia, 2011

The author would like to thank TWI for their permission to use data from TWI Report 485/1994 in this presentation.

THANK YOU

ANY QUESTIONS?

INGENIOUS SIMPLICITY