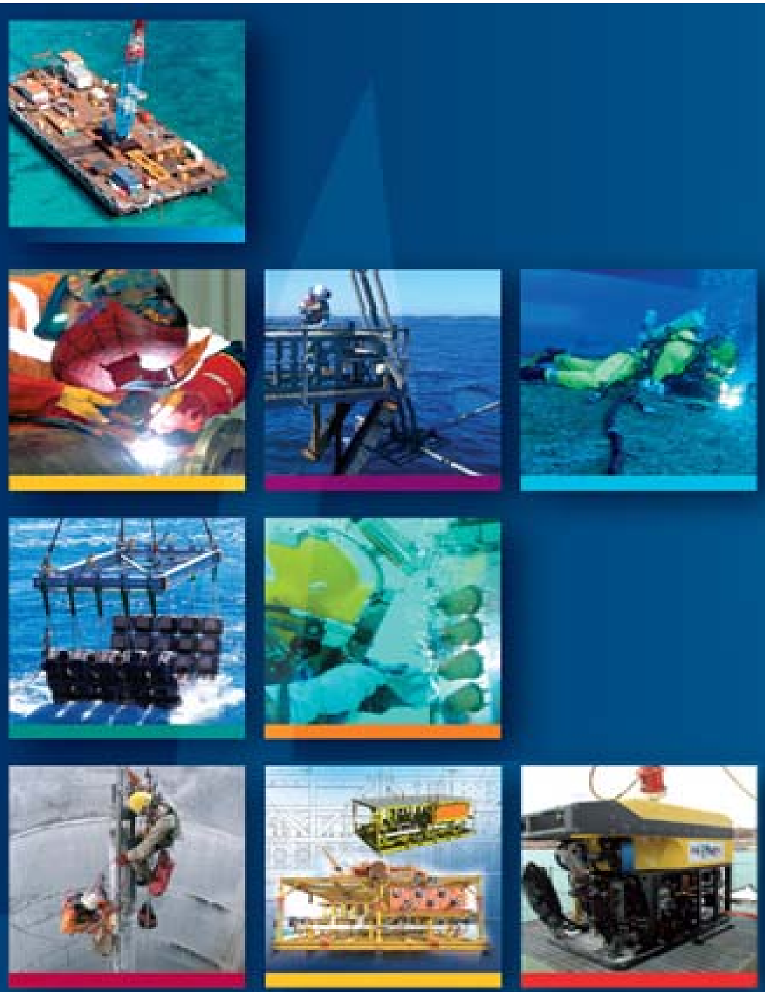

Use of Underwater Dry Welding for In-Situ Repair to Offshore Structures

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In-Situ Welding

- Steel Structures
- Suitability of Repair Methods
- Mobile Offshore Units
  - Dry Docking Schedule (Inspection and Repair)
  - Underwater Inspection In-Lieu of Dry Dock (UWILD)
- Fixed Offshore Units

Difficulties in Welding

- Welding Challenges

- Diver and Operational Challenges

Welding Challenges

- Water
  - Rapid Cooling Rates
  - Hydrogen
  - Cracking
- Ambient Pressure
  - Porosity
- Material
  - Higher carbon content (Older)
  - Alloyed Steels

No Shielding Gas on Steel. [Online]. [Accessed 23 February 2015]. Available from: http://www.millerwelds.com

Operational Challenges

- Welder Challenges
  - Environment
    - Sea state and current
    - Visibility
  - Weld Location
    - Access to Weld Area
    - Fatigue
  - Technique

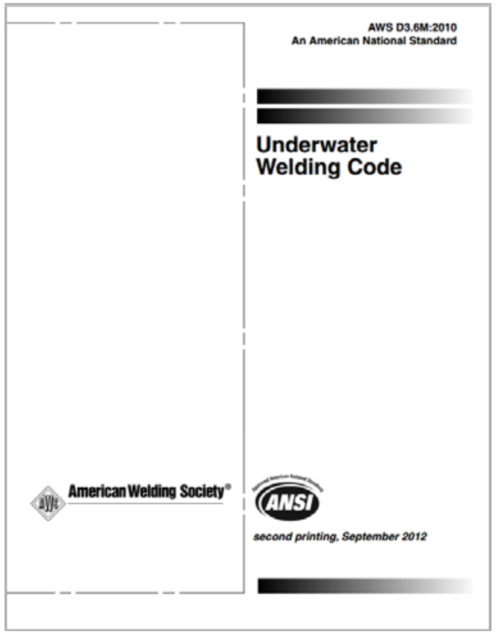
- Repair Time Challenges
  - Diving weather window
  - Depth limited dive time

Welding Codes

- Welding Procedure Specification

- Classification Body Codes
  - DNV GL
  - ABS
  - Lloyd's Register
  - Bureau Veritas

- AWS D3.6 – Underwater Welding Code (2010)
  - Weld Classification
    - Class A – suitable for comparable applications to surface welding
    - Class B – suitable for less critical applications and fitness for purpose
    - Class O – meet additional code or standard requirements

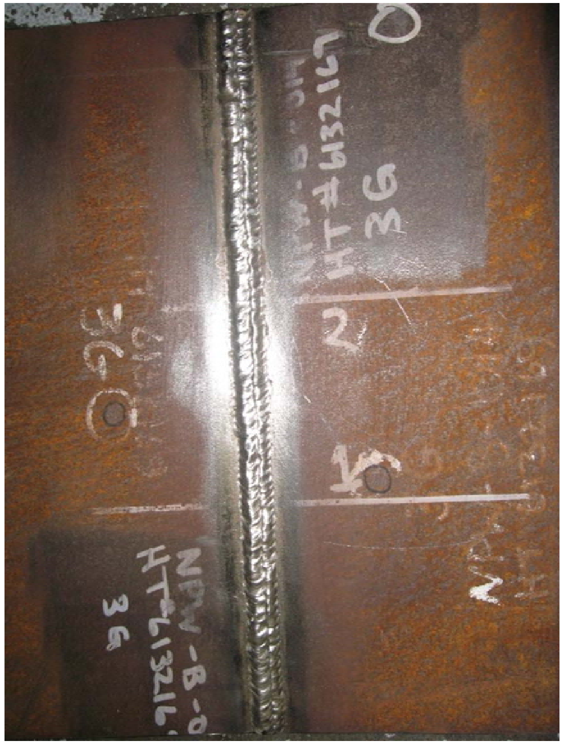


Welding Procedure Specification

A document which outlines the steps to be followed to produce a weld with the required properties.

Some Essential Variables:

- Depth
  - Ambient Pressure
- Steel chemical composition (Carbon and Carbon Equivalent)
  - Hardenability (350HV10)
- Welding consumables
- Pre- and Post- Heating



Weld Classes

	Class A	Class B
Visual Inspection / Surface Inspection	No visible cracks, porosity, or inclusions	No visible cracks
	Maximum undercut 1.5mm	Maximum undercut 3mm
Material Properties	Weld metal yield and tensile strength to meet or exceed base material specification	Weld metal tensile strength to meet or exceed base material specification
	Hardness below 325HV10	Hardness below 375HV10
	For specified tensile strength below 485MPa, average impact of 27J (minimum 14J)	For specified tensile strength below 485MPa, average impact of 20J (minimum 14J)
Non-Destructive Testing	Radiographic Testing	Radiographic Testing
	Ultrasonic Testing	

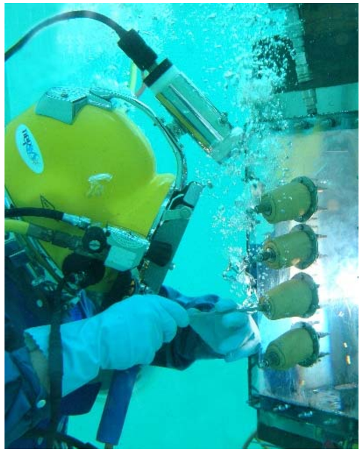
Methods of Underwater Welding

Wet Welding

- Welding arc and weld is not separated from the water

Dry Spot Welding – NEPSYS

- Weld is separated from the water
- Diver is separated from the weld



Hyperbaric Welding

- Weld is separated from the water
- Diver is not separated from the weld

Welding Method Comparison

	Wet	Dry Spot (NEPSYS)	Hyperbaric
Typical Quality	Class B	Class A	Class A
Repair Depth	Achieved up to 100m	Achieved up to 60m	Achieved up to 400m
Repair Materials	Carbon Content <0.1%, and Carbon Equivalent <0.37%	Restrictions comparable to surface welding	Restrictions comparable to surface welding
	Limited wet welding specific electrodes	Variety of electrodes may be used	Variety of electrodes may be used
Application	Almost nil restrictions to weld area geometry	Some restrictions due to habitat size and weld area geometry	Restrictions due to chamber size and weld area geometry
Safety	Welder mobility	Welder mobility	Separation of Welder and water
		Separation of Welder and weld	

Typical Commercial Comparison

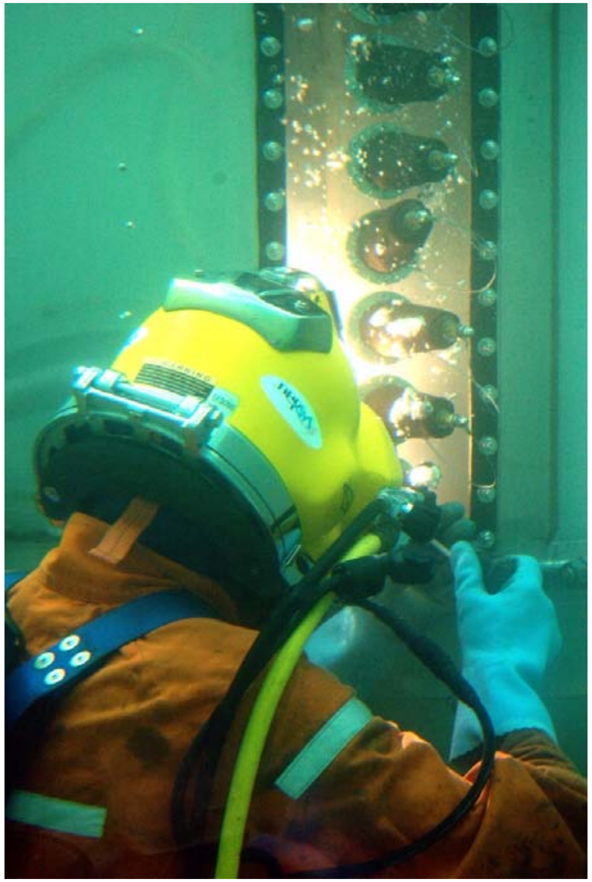
<table>
<tr><th></th><th>Wet</th><th>Dry Spot (NEPSYS)</th><th>Hyperbaric</th></tr>
<tr><td rowspan="2">Qualification and Set Up</td><td colspan="3">Weld and Welder qualification</td></tr>
<tr><td></td><td>Small habitat design / fabrication</td><td>Large chamber design / fabrication</td></tr>
<tr><td rowspan="3">Project Mobilisation</td><td colspan="3">Personnel</td></tr>
<tr><td colspan="3">Diving spread</td></tr>
<tr><td>Welding equipment and consumables</td><td>Welding / habitat equipment and consumables</td><td>Welding / chamber equipment and consumables</td></tr>
<tr><td rowspan="3">Operations</td><td colspan="3">Vessel / personnel</td></tr>
<tr><td rowspan="2">Welding speed comparable to surface welding</td><td>Habitat set up / removal by divers</td><td>Chamber set up / removal by vessel crane</td></tr>
<tr><td>Reduced Welding Speed</td><td>Welding speed comparable to surface welding</td></tr>
</table>

Typical Commercial Comparison

	Wet	Dry Spot (NEPSYS)	Hyperbaric
Qualification and Set Up	Days to Weeks	Weeks to Months	Months
	Low Cost	Medium Cost	High Cost
Project Mobilisation	Days to Weeks	Days to Weeks	Weeks
	Low Cost	Low to Medium Cost	High Cost
Operations	Small Vessel	Small Vessel	Larger Vessel including crane
	Low number of dives	Medium number of dives	Low number of dives

Case Study - NEPSYS System

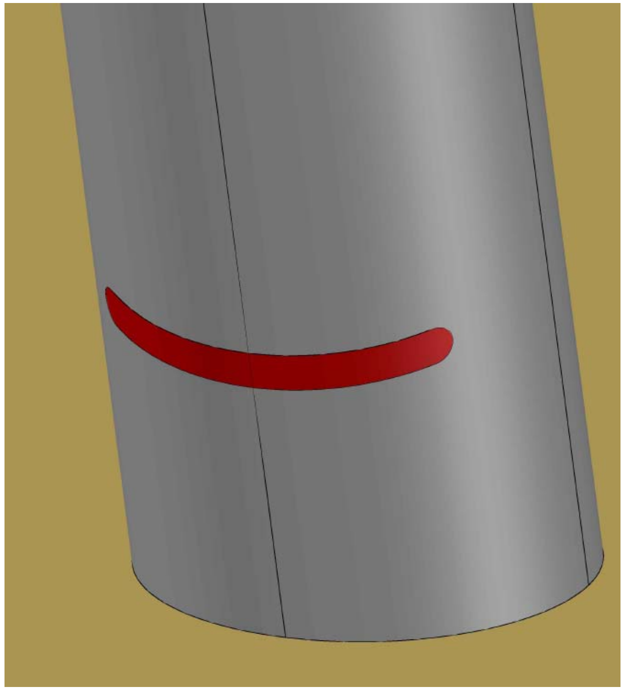
- Habitat which isolates the weld area is designed.
  - Accommodates the geometry of the area surrounding the weld
  - Incorporates windows for visibility and access to the weld
- Heated gas displaces the water, creating a dry, protected environment for welding
- Welding Rods are coated and hermetically sealed to protect from the environment before being used in welding



Case Study

- 1.5m diameter raked pile
- Approximately 25% of the circumference was damaged at -17m LAT
- Damage to the underside of the pile
- Contacted by client in August
- Grouting of piles in October

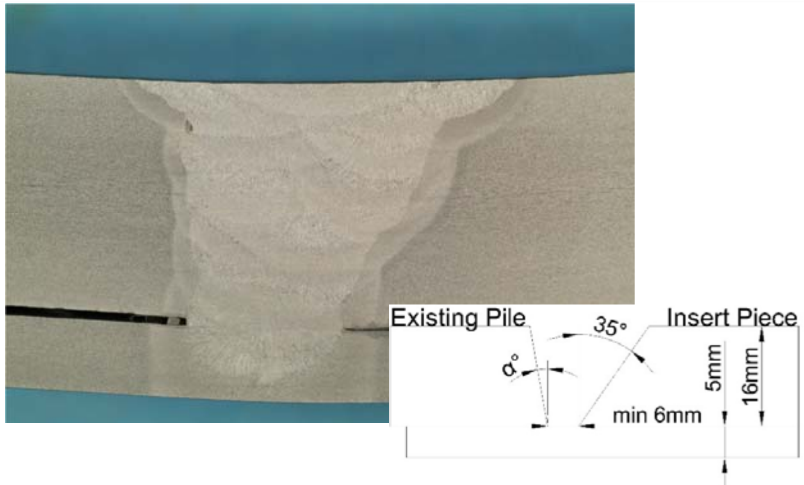
- Options for repair:
  - Removal and Re-piling
  - Clamp
  - Repair Patch via wet weld
  - Reinstatement of Material via dry welding



Welding Qualification

- Base Steel had high Carbon Content 0.18% (CE 0.44%)
- Initial Hardness Testing – Maximum 276HV10

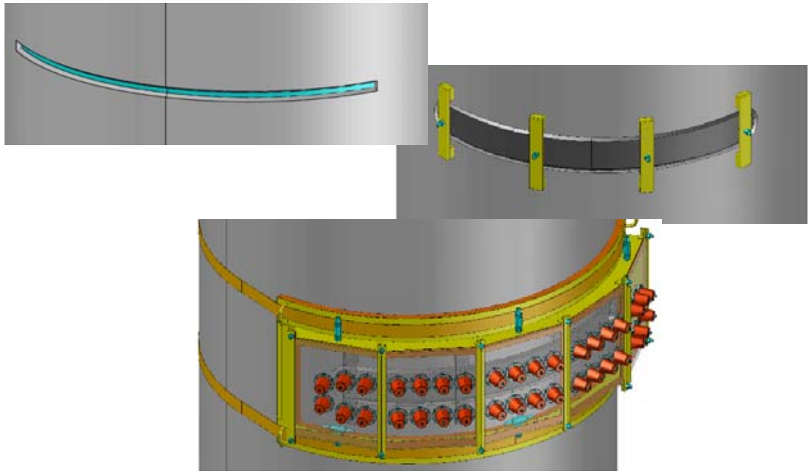
- Weld preparation designed to minimise welding time
- Procedure qualification in the Vertical and Overhead positions over three weeks
- Qualification in Perth witnessed by third party
- Multiple welder qualification



Insert Plate and Habitat Design

- Insert plate design adapted for damage profile, welding procedure
- Habitat design adapted for insert plate profile
- Habitat fabrication (one week)

- Removal of damaged area via water jetting which left edges suitable for welding
- Insert plate installation allowed progression of grouting works

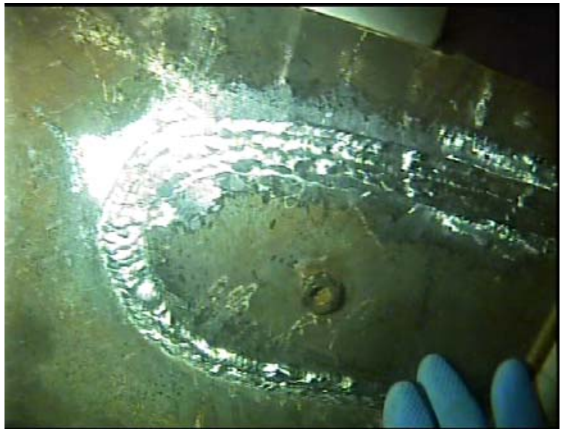


Operations

- Mobilisation from Perth to Queensland of NEPSYS equipment and personnel
- Operations conducted with local dive spread
- Diving from the back of a 15m work boat
- Nitrox mixture used to ensure longer dive times at the repair depth
- Four qualified welders
- Approximately 45 hours of welding
- 2800mm of weld in 16mm plate

Results

- Weld ground flush to the pile
- No surface defects found via Magnetic Particle Inspection or Creep Wave Ultrasonic Testing
- No subsurface defects found via Shear Wave Ultrasonic Testing or Time of Flight Diffraction
- Damaged area fully removed from the pile and reinstated
- Design strength of the pile restored



Conclusion

- In-situ repair options
- Suitability of Welding Methods
- Questions?