STRUCTURAL INTEGRITY SERVICES

HYDRA-LOK™ Connections

Oil States™

STRUCTURAL INTEGRITY & ABANDONMENT SERVICES

HYDRA-LOK™ Connections

Structural Connections History

The structural connection described in this brochure uses the Oil States Industries patented HYDRA-LOK™ swaging system, which has been used for forming pile connections on offshore structures, repairs to platform seawater / firewater caissons, conductor and casing. The technology has also been adapted to perform localised pressure tests on casing joints; pipeline flanged / welded joints and emergency shutdown valves. First developed in the 1980's, the Pile swaging system has been used on hundreds of structures ranging from subsea Drilling Templates to Large Deepwater Jackets.

HYDRA-LOK LITE™ is a variant of the system that has been developed specifically for smaller subsea protection structures where lower connection load capacities are required. For casing applications the system provides a connection that is both pressure-tight and as structurally strong as the parent casing.

- Oil States Industries is registered to ISO 9001: 2015, ISO 14001: 2015 and OHSAS 18001:2007
- HYDRA-LOK™ tooling is available to form connections on standard pile sizes ranging from 24" diameter to 84" diameter having a diameter to wall thickness ratio (d/t) between 20:1 and 40:1
- The connection method has "Type Approval" by Lloyds Register and "Approval in Principal" by DNV
- Bureau Veritas, The American Bureau of Shipping (ABS) and the Russian Maritime Register of Shipping (RMRS) have all certified structures using swaged pile connections
- Typically, a connection can be formed and examined using the swage tool's built-in inspection system in 2 hours
- Typically, a 4-pile structure including equipment handling can be secured in 8 to 10 hours
- All swage tools and auxiliary equipment are tested to the required project operating pressure at a depot of oil States Industries ahead of mobilisation offshore
- Swage tools can be integrated with the Latch-Lok jacking system allowing structures to be levelled and secured in a single tool deployment operation

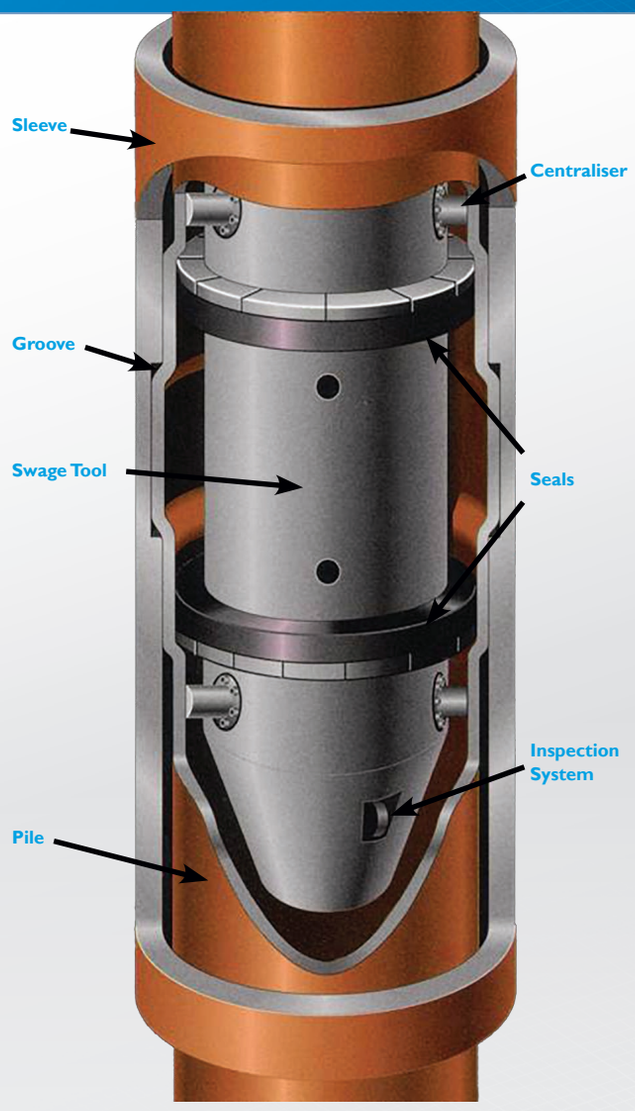
HYDRA-LOK™ Pile Connection Technique

HYDRA-LOK™ Principle

The basic concept of the HYDRA-LOK™ swage pile connection system is simple. Two tubulars, the pile and a sleeve fabricated to the structure, are connected through the hydraulic expansion of the pile into the sleeve. Depending upon the pile size, it typically takes between 1 and 2 hours to form the swaged connection, which has immediate full-strength capacity on expansion of the pile into the sleeve and release of the hydraulic pressure. The technology can be used to secure any type of offshore structure having piled foundations. Typically Subsea Protection Structures, Pre-Drilling Templates and small Manifolds utilise 24" dia. to 36" dia. pile size connections; Shallow Water Jackets and Large Subsea Templates have 36" dia. to 60" dia. pile size connections and Ice Resistant Platforms, Deep Water Jackets and Wind Turbine Generators are secured using 60" dia. to 84" dia. pile size connections.

Single Operation Structural Levelling and Pile Connection using 60" HYDRA-LOK™ and Latch-Lok Jacking Tool

Jacket Installation in SNS 60" Swage Pile Connections



The pile is fully expanded over the distance between the Swage Tool Seals to take up the annular clearance between the two tubulars and make full contact with the sleeve bore

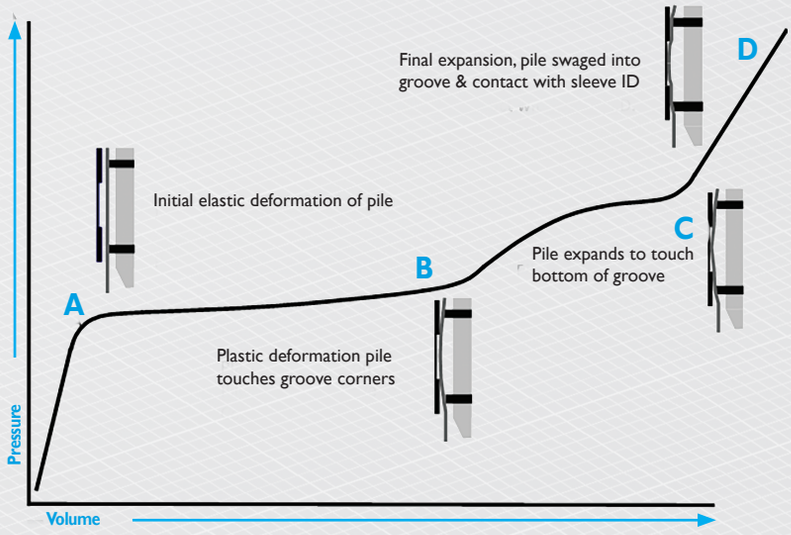
Operational Sequence

The operational sequence for installing an offshore structure using the HYDRA-LOK™ system is to set the structure on the seabed, drive the piles and deploy the HYDRA-LOK™ swage tool subsea to form the connections. Once subsea, the swage tool is stabbed into the pile and positioned within the sleeve relative to the pile top elevation. The swage tool is then centralised and isolation seals inflated, trapping an annulus of water between the tool and pile which is subsequently pressurised to expand the pile into the sleeve grooves. Once formation of the connection is complete, the swage tool inspection system is activated to confirm the correct connection geometry as the tool is lifted from the pile. The HYDRA-LOK™ tool is then transferred to further piles and the process repeated until all connections have been formed.

Operational Control

The swaging operation is a continuous process which is accurately controlled with all engineering associated with the connection formation being completed ahead of mobilisation. A Pressure/Volume or P/V plot is used to control the operation and enables the operator to visualise the process in real time. The swaging process is accurately and simply monitored by measurement of the pressure and volume of water pumped into the annulus between the pile and tool seals. The onshore engineering completed ahead of mobilisation uses the material test certificate data together with dimensional inspection survey results for fabricated piles and sleeves to accurately calculate the final swage pressure and volume required to form the connection.

The P/V plot shows the distinctive stages of the expansion process, firstly through the initial elastic expansion of the pile, followed by its yield and plastic expansion to contact the internal diameter of the sleeve. The expansion continues with the pressure increase as the pile is forged into the bottom of the groove and against the sleeve bore up to the elastic limit of the sleeve material. When the calculated final pressure is reached, the process is complete and the connection is formed. Upon releasing the pressure, the sleeve contracts elastically onto the pile creating an interference fit (see diagram below, showing the cut-out section through a 2 groove swaged connection). Axial loads and bending moments are transferred from the structure into the pile though the loading across the groove corners and the frictional forces generated between the two tubulars on release of the hydraulic swage pressure.



Operational Control of Connection Formation – Pressure Volume Plot

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HYDRA-LOK™ Connections

Operational Advantages

- Real-time verification of connection formation
- Rapid full-strength connection
- Fast, reliable operations, reduced marine spread time
- Environmentally friendly, pollution-free
- Diverless - any current, any depth
- Short connection length saving pile weight and cost

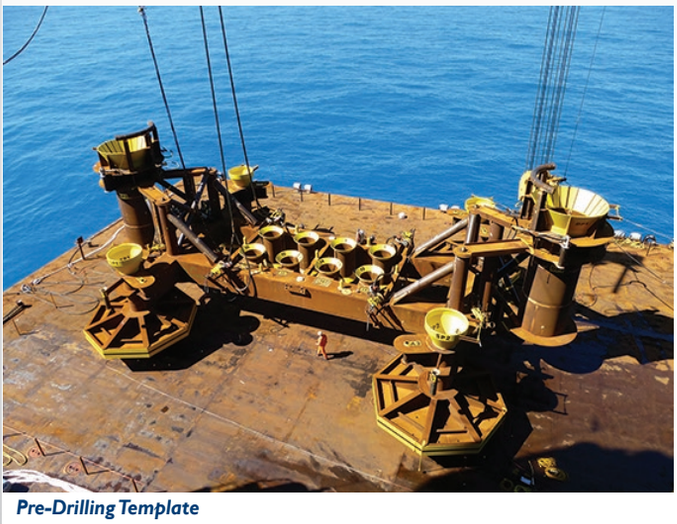
Cut-out Section through a 2 groove HYDRA-LOK™ Connection

HYDRA-LOK™ Connection Capacities

A firm and fixed connection between pile and structure is essential for platform stability and is necessary for approval by certifying authorities. In order to achieve Lloyds 'Type Approval' extensive testing of the HYDRA-LOK™ connection was carried out during the development program. This included establishing basic compression, tension and bending strengths plus a separate Joint Industry Study program of testing to investigate the fatigue performance of the connection. Other studies and tests included metallurgy testing on parent and weld metal subjected to the swaging process and the corrosion behavior of the completed connection. All work was supervised and witnessed by Lloyds Register of Shipping to gain 'Type Approval' of the technique and was followed by 'Acceptance in Principle' from DNV. It has since been approved for use on projects by Bureau Veritas, American Bureau of Shipping (ABS) and the Russian Maritime Register of Shipping (RMRS).

Subsea Manifold

84" HYDRA-LOK™ Double Groove Sleeves (Machined)



Pre-Drilling Template

HYDRA-LOK™ connection sleeves are fabricated from standard offshore structural steels (EN10225 S355 G8+N, Z35) with the number of sleeve grooves required depending upon the axial capacity required from the connection.

Approved sleeve manufacturing methods:

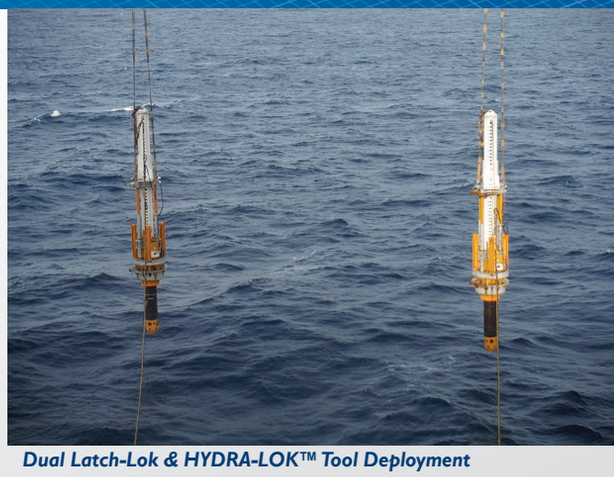
- Type 1: Machined from rolled and welded plate

  The sleeve is rolled and fabricated from plate with sufficient wall thickness to enable a machined bore to be achieved to the specified dimensions and tolerances while maintaining the required minimum wall thickness.
- Type 2: Two thicknesses of plate rolled and welded into rings

  The rings are welded together to produce the required sleeve geometry. No machining is associated with this option and the project drawings will indicate the plate thicknesses needed for producing the internal profile.

Certifying Authority approved axial load capacities for 1, 2, 3 & 4 grooved connections at various pile sizes

Pile Size (inches)	Wall Thickness (inches)	Connection Axial Load Capacity (Tons)			
		1 Groove	2 Groove	3 Groove	4 Groove
24	0.75 to 1.25	232 to 379	330 to 538	465 to 758	697 to 1137
30	0.75 to 1.5	292 to 570	415 to 810	585 to 1139	877 to 1709
36	1.0 to 1.75	466 to 799	663 to 1135	933 to 1597	1399 to 2396
42	1.0 to 2.0	546 to 1066	776 to 1515	1093 to 2132	1639 to 3198
48	1.25 to 2.0	779 to 1226	1107 to 1742	1557 to 2452	2336 to 3678
54	1.35 to 2.5	947 to 1716	1346 to 2438	1894 to 3431	2841 to 5147
60	1.5 to 3.0	1169 to 2279	1662 to 3238	2339 to 4557	3508 to 6836
72	1.75 to 3.5	1638 to 3195	2328 to 4540	3276 to 6390	4915 to 9584
84	2.0 to 4.0	2185 to 4264	3106 to 6060	4371 to 8528	6556 to 12792



Dual Latch-Lok & HYDRA-LOK™ Tool Deployment

Ice Resistant Platform Installation – 84" pile connections

HYDRA-LOK LITE™ for Subsea Structures

The HYDRA-LOK LITE™ "swaged" connection is a simple interference-fit sleeved joint between two plain steel tubulars, which is formed by locally expanding the inner tubular (pile) to contact the surrounding outer tubular (sleeve). The expansion process is then continued to induce a small plastic deformation or "bulge" in the outer sleeve, typically 1% to 2% of diameter. The connection has been developed as an alternative to the existing HYDRA-LOK™ structural pile connection (heavy wall "grooved" sleeve arrangement), and is typically used on small subsea structures where the pile connection axial load requirement is low (typically 100 Tonne or less) and connection deflections are not critical.

On releasing the hydraulic pressure used to form the swaged connection, the sleeve elastically contracts onto the pile to generate an interference fit connection between the two tubulars. The resulting connection capacity can be varied significantly through the use of dissimilar strength steels for the pile and sleeve, for example; EN10225 S355 grade pile and EN10225 S460 grade for the sleeve.

Offshore Operation

After positioning the HYDRA-LOK LITE™ swage tool within the pile/sleeve, the main seals are inflated by pumping water from the surface power pack via a service umbilical. The seals are expanded to contact the inside of the pile thereby trapping an annular volume of water around the tool centre body. This "annulus" and the seals are then pressurised together to expand the pile and the surrounding sleeve. During the pressurisation process, pressure (P) and volume (V) readings are recorded and plotted to produce a P/V plot, which provides a "real-time" means of monitoring and verifying the swaging process. On completion of the swage, the hydraulic pressure is released at the tool to allow the seals to retract, before the tool is withdrawn from the pile.

The time taken to make a single HYDRA-LOK LITE™ connection is around 30 minutes, and a single 4-pile structure can normally be swaged within a total deck-to-deck time of 8 hours.

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HYDRA-LOK™ Connections

Section through 9-5/8" Casing Swaged Test Specimen

Internal view on completed Swage

Benefits

- Real-time verification of connection formation
- Rapid full-strength connection
- Fast, reliable operations reduce marine spread time
- Environmentally friendly and pollution-free
- Diverless - any current, any depth
- Short connection length, saves pile weight and cost
- Reduced equipment spread and fewer personnel reduce cost with respect to HYDRA-LOK™

HYDRA-LOK™ Connections

Expandable Tubular System for Casing Connections

- Pressure testing
- Internal casing patch
- External tie back connection
- Zonal isolation barrier
- Expandable liner hanger

HYDRA-LOK™ sealing/tubular expansion technology has a 38-year track record covering pile swaging, localised pressure testing and caisson repair operations. Most of these activities involve working pressures below 10,000 psi (690 bar), but the basic HYDRA-LOK™ sealing arrangement is capable of operating at pressures in excess of three times this value. This capability is now being exploited for casing and pipeline repair applications.

HYDRA-LOK™ casing connection system utilises the higher working pressure capability to "cold forge" pressure-tight, metal-to-metal connections (such as casing "cross-over" joints) or localised pressure testing.

The system was initially developed for a casing patch application, the aim being to use a HYDRA-LOK™ tool to expand the top end of a slumped casing into a multi-groove, over-shot sleeve fitted to the foot of a new casing string. The swaged connection produced by this process is clearly illustrated in the adjacent photographs. A feature of the system is that, after forming the connection and without the necessity of recovering it, the tool can be re-positioned to span the joint interface and then used to internally pressure test the connection to its full test pressure.

Development testing was carried out on 5" O.D. L80 and P110 casings, and subsequently on 9 5/8" O.D. P110 and XT155 casings. As a result of this work, optimised sleeve geometry was derived and a HYDRA-LOK™ tool built, that can make a 9 5/8" casing connection in around 35 minutes and operate at pressures up to 35,000 psi (2,414 bar). The final P110 test connection was pressurised to an internal pressure of 11,000 psi (759 bar) whilst simultaneously loaded to 620Te with entirely satisfactory results.

Case Study (Agip) - Cross-over Connection Installation

This project consisted of two onshore wells, where the casing configuration needed to be changed some 200 m below ground level. The plan was to carry out an explosive back-off at the required elevation on an existing 9 7/8" T95 casing joint, recover the upper casing, run in with a new 10 3/4" casing string and make up to the 9 7/8" T95 casing using a standard cross-over sub. As a contingency, the 9 7/8" casing could be cut and then swaged into a new 10 3/4" casing string with the HYDRA-LOK™ multi-groove over-shot sleeve being the cross-over joint.

The existing 9 5/8" swage tool was modified for drill string deployment and remote operations, and a full 9 7/8" T95 test connection was made prior to mobilisation to the site. The test connection was successfully tested to 300 Te axial load with simultaneous 3,000 psi internal pressure.

Features

- New casing run with overshot HYDRA-LOK™ sleeve
- Existing steel casing swaged into overshot sleeve
- HYDRA-LOK™ tool run on drill pipe
- Connection made and tested in a single deployment
- Casing material up to 155 ksi yield connected
- Metal to metal seal
- No reduction in I.D.

Case Study (Total) - Pressure Testing

On another project, the client wanted to pressure test some suspect 10 3/4" casing joints in five offshore High Temperature/High Pressure wells. In each well, the HYDRA-LOK™ tool was deployed on the drill string to a depth of approximately 300 m and located such that it spanned the suspect casing joint. The seals were inflated and the tool pressurised to carry out the necessary localised pressure integrity tests. Each joint was subjected to a hydrostatic pressure test at 11,000 psi followed by a gas pressure test at 5,000 psi without the need for tool recovery.

The tool for this project was purpose built, using the existing main sealing systems from the 9 5/8" swage tool. As part of the Factory Acceptance Trials ahead of mobilisation, the tool was pressure tested to 15,000 psi using water and 6,500 psi using nitrogen.

Filanovsky Field, Caspian Sea, Ice Resistant Platforms

84" HYDRA-LOK™ Deployment

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