Title: APPARATUS FOR FORMING TUBULAR CONNECTIONS AND METHOD OF USE

Abstract: The invention in one aspect provides an apparatus and method for forming a connection between an inner tubular and a caisson of an offshore structure. The apparatus comprises a mandrel, and a seal arrangement disposed on the mandrel and configured to form a seal between the mandrel and an inner surface of an inner tubular in which the apparatus is located. The seal arrangement comprises first and second cup seals, axially separated on the mandrel, and configured to define a substantially annular volume between the mandrel and the inner tubular in use. A pressure transmission path delivers a pressurised fluid to the annular volume, and the apparatus is configured to pressurise the annular volume and thereby expand the inner tubular in a radial direction and into contact with the caisson to form a connection between the inner tubular and the caisson.

Fig. 1A
APPARATUS FOR FORMING TUBULAR CONNECTIONS AND METHOD OF USE

The present invention relates to an apparatus for the connection of tubulars and methods of use, and in particular to an apparatus for forming swaged connections of tubulars, and methods of use in caisson repair operations.

Background to the invention

A caisson is a column or chamber, generally formed of steel or concrete, which serves as a foundation for offshore structures or a protective surround for subsea equipment. Many mature or existing offshore structures and platforms suffer from significant integrity-related problems associated with caissons, which in some cases can result on severance of parts of the caisson structure. This can pose a significant risk to surrounding subsea infrastructure, such as pipelines and risers.
There are currently a variety of options available to repair a caisson, which have varying levels of effectiveness, cost and technical complexity. One approach to the repair of offshore caissons is to use an internal swage repair method. In general terms, such methods involve running a tubular liner into the caisson, and expanding the tubular liner to form a swaged connection with the caisson either side of the affected area.

An example of an apparatus and method used in caisson repair applications is described in US Patent Number 4,608,739. US 4,608,739 describes a tool and a method of use which includes a force transmitting sleeve of solid deformable material defining an internal recess for receiving a fluid under pressure. The tool also comprises anti-extrusion means associated with the sleeve to limit extrusion of the sleeve in an axial direction during use.

The system of US 4,608,739 is stated to overcome known deficiencies of previously proposed systems. These include previously proposed systems which expand a section of pipe radially by sealing off that section and applying a high pressure fluid directly to the internal surface of that section. US 4,608,739 describes that with this approach it is extremely difficult to provide an effective seal unless expensive and complicated sealing systems are utilised. In particular, US 4,608,739 states that it is expected that it would be impossible to achieve a sufficient seal to allow effective deformation of the outer tubular.

It is known to expand and connect tubulars in downhole applications. For example, US 2004/0031615 describes a system for forming a swaged connection between a cladding to create a seal with a downhole tubular. The described system uses a tool with an axially separated pair of cup seals, defining an annular volume in which fluid pressure is applied to deform the cladding. While this arrangement is proposed for downhole connection of tubulars, it is unsuitable for caisson repair applications, which have outer diameters significantly larger than the diameters of downhole tubulars. Indeed, typical caisson outer diameters of 20 inch, 26 inch, 36 inch present particular technical issues. Large diameters require corresponding large pressures in order to create a swaged connection. In contrast to downhole applications, where the internal tubular is only required to expand up to the internal diameter of the casing, the caisson repair application needs to take into consideration the specification combination of wall thickness, material yield strength, asset wave data, and the support configuration of each caisson in order to determine the required pressure and volume to create an effective swage. Determining the limits of acceptable permanent deformations in the caisson that will allow the swage
connection to carry the weight of the repair liners, the caisson defect section, and dynamic loads from the waves is a complex issue, which does not apply to downhole applications.

Other drawbacks of previously proposed caisson repair systems include the reliance on non-uniform tubing profiles to create an effective connection. For example, to form a sufficient connection within the pressure ranges within the limitations of available seals, it will be necessary in some applications for the liner and/or the caisson to have non-uniform thickness or special formations. For example, in some applications, the inner surface of the caisson is provided with an annular recess, nipple profile or other formation to enable an inner liner to be deformed into the recess to form a connection. Other caisson repair system use liners with non-uniform thickness or thinner portions to enable expansion into contact with the caisson. The reliance on an outer recess limits the applicability of the technology to pre-defined location, and the use of non-uniform thickness tubulars significantly increases manufacturing costs, and therefore the overall cost of the repair operation. US 2004/0031 615 also utilises a pattern of teeth on the outer surface of the cladding to provide mechanical grip between the cladding and the tubular.

Summary of the invention

It is amongst the aims and objects of the invention to provide an apparatus and/or method for forming tubular connections, which obviates or mitigates one or more drawbacks or disadvantages of the prior art.

In particular, one aim of an aspect of the invention is to provide an apparatus and/or method for forming swaged connections between a caisson of an offshore structure and an inner tubular, which obviates or mitigates one or more drawbacks or disadvantages of the prior art.

Other aims and objects of the invention will become apparent from the following description.
According to a first aspect of the invention, there is provided an apparatus for forming a connection between an inner tubular and a caisson of an offshore structure, the apparatus comprising:

- a mandrel;
- a seal arrangement disposed on the mandrel and configured to create a seal between the mandrel and an inner surface of the inner tubular in which the apparatus is located;
- wherein the seal arrangement comprises first and second cup seals, axially separated on the mandrel, and configured to define a substantially annular volume between the mandrel and the inner tubular in use;
- a pressure transmission path for delivering a pressurised fluid to the annular volume;
- wherein the apparatus is configured to pressurise the annular volume and thereby expand the inner tubular in a radial direction and into contact with the caisson to form a connection between the inner tubular and the caisson.

The terms "upper" and "lower" are used herein to indicate relative axial positions on the apparatus.

The inner tubular may be a liner. The inner tubular may be of substantially uniform thickness. Alternatively, the inner tubular may be of non-uniform thickness.

Preferably, the caisson is a metal caisson, and most preferably, is a steel caisson.

The mandrel may be substantially cylindrical in form. The mandrel may be at least partially hollow.

The first and second cup seals may be disposed on the mandrel. The first and second cup seals may be upper and lower cup seals.

The first and second cup seals may each comprise a cup member. One or both cup members may be formed from a flexible, elastomeric material. One or both cup members may be formed from rubber. One or both cup members may be formed from nitrile butadiene rubber (NBR). The material of one or both cup members may have hardness between 75 and 85 on the Shore A hardness scale. In one embodiment, the material of one or both cup members has hardness of approximately 80 on the Shore A hardness scale.
An inner surface of a cup member may be substantially cylindrical. One or both cup members may define an open end. An inner surface of each cup member may be substantially cylindrical at the open end.

One or both cup members may further comprise a neck portion. The neck portion may be substantially cylindrical, and/or may be of reduced inner diameter and/or reduced outer diameter relative to the maximum outer diameter of the cup member, and/or relative to the open end of each cup member.

The maximum outer diameter of a cup member may be defined at the open end of the cup member. Alternatively, the maximum outer diameter of a cup member may be defined at an intermediate point on the outer surface of the cup member, between the open end and the neck portion.

The outer surfaces of one or both cup members may define one or more substantially conical shapes. An outer surface of a cup member may be tapered towards a maximum outer diameter of, which may define a substantially conical shape between a neck portion of the cup member and its maximum outer diameter. In addition, the outer surface of a cup member may be tapered towards its open end, which may define a substantially conical shape between its maximum outer diameter and its open end. Alternatively, the outer surface of each cup member may be tapered towards its maximum outer diameter, which may define a generally conical shape between its neck portion and its maximum outer diameter, which may be defined at its open end.

The inner surface of a cup member may define a substantially annular recess. The inner surface of a neck portion of a cup member may define a substantially annular recess. The mandrel may extend through the annular recess defined by the inner surface of a cup member. Contact between the inner surface of a cup member and the mandrel may define a closed end of a cup member.

The first and second cup seals may be axially separated on the mandrel such that the open ends of the cup members face towards one another. The first and second cup seals may be axially separated on the mandrel such that the neck portions of the cup seals are positioned axially farthest away from one another. The first and second cup seals may be
axially separated on the mandrel such that the closed ends of the cup seals are positioned axially farthest away from one another.

A cup member may be provided with a reduced inner diameter portion. The mandrel may comprise a recess, or recesses, which correspond in shape and size to the reduced inner diameter portion of a cup member such that the reduced inner diameter portion of a cup member may axially engage with the corresponding recess on the mandrel, to ensure that a cup member is fixed axially in position on the mandrel.

The substantially annular volume may be formed between the first and second cup seals, the outer surface of the mandrel, and the inner surface of the inner tubular.

The apparatus may further comprise retaining rings. The retaining rings may assist with retaining and/or fixing the first and second cup seals and/or any other components of the apparatus in axial position on the mandrel. The retaining rings may be an upper retaining ring and a lower retaining ring and may be disposed axially above and below the seal arrangement.

One or both retaining rings may comprise a substantially cylindrical body which may define an annular recess. The retaining rings may be formed from a metal which may, for example, be steel.

One or both retaining rings may comprise a reduced inner diameter portion. The mandrel may comprise a recess, or recesses, which may correspond in position, shape and size to the reduced inner diameter portion of one or both of the retaining rings such that the reduced inner diameter portion a retaining ring may axially engage with a corresponding recess on the mandrel. Alternatively, the inner diameter of the seal retaining rings may be uniform or substantially uniform.

The apparatus may be provided with more than two retaining rings.

The first and/or second cup seals may further comprise an anti-extrusion member, which may function to reduce or prevent the material of each cup member of the first and second cup seals from flowing. In particular, the anti-extrusion member may function to reduce or prevent the material of a cup member from flowing axially outwards (i.e. in a longitudinal
direction away from the annular volume) between the inner tubular and the components of
the apparatus,

An anti-extrusion member may be substantially annular in form and may partially surround
the outer surface of a cup member of the first and/or the second cup seal. The inner
surface of an anti-extrusion member may abut at least some of the outer surface of a cup
member. An anti-extrusion member may extend from the closed end of a cup member,
partially along the outer surface of a cup member towards the open end of a cup member.
The anti-extrusion members may be formed from a material which is harder than that of
the cup members.

An anti-extrusion member may be formed from rubber. An anti-extrusion member may be
formed from nitrile butadiene rubber (NBR). The material of an anti-extrusion member
may have hardness between 85 and 95 on the Shore A hardness scale. In one
embodiment, the material of the anti-extrusion members has hardness of approximately 90
on the Shore A hardness scale

An anti-extrusion member may further comprise a spring. Preferably, an anti-extrusion
member further comprises a helical garter spring. The spring may be embedded within an
anti-extrusion member and may extend circumferentially around an anti-extrusion member
and/or a cup member upon which the anti-extrusion member is provided. The spring may
comprise a core of a harder anti-extrusion material which may reduce the risk of a cup
member material from flowing into and within the spring.

One or both of the cup members may be selectively bonded to the apparatus or the
components thereof. A cup member may be selectively bonded to at least one of: the
retaining ring, the anti-extrusion member and the spring. Selective bonding may permit
relative movement at contact areas between the components of the seal and/or the
apparatus. Bonding may be achieved using an adhesive. The majority of the contact
surfaces between an anti-extrusion member a cup member may be unbonded.

The pressure transmission path may comprise: a fluid fill valve, vent valves, a fluid drain
path comprising a fluid drain valve, a flow meter for measuring the volume of fluid flowing
through the system, and air bleed valves.
The apparatus may further comprise a support pin assembly. Preferably, the apparatus
comprises a support pin assembly at its lower end, positioned axially below the seal
arrangement.

The support pin assembly may comprise a number of support pins which may be operable
to extend radially outwards from the apparatus. Preferably, the support pin assembly
comprises a pair of support pins which are arranged with their longitudinal axis
perpendicular to that of the apparatus, with an azimuth angle of 180 degrees between
them.

The support pin assembly may have a retracted condition, in which the support pins may
be retracted into a body of the support pin assembly such that they do not substantially
extend radially outwards past the maximum outer diameter of the apparatus and/or of the
cup seals of the seal assembly. The support pin assembly may also have an extended
condition, in which the support pins may extend radially outwards from the apparatus, past
the maximum outer diameter of the apparatus and/or the cup seals, and in which they may
contact the inner tubular in use. The inner tubular may comprise slots, apertures and/or
recesses which correspond to the size, shape and location of the support pins (when
extended), such that the support pins may extend into the slots, apertures and/or recesses
in the inner tubular. The support assembly and/or the support pins, in their extended
condition, may bear the load of the inner tubular and any additional loads associated with
the inner tubular.

The support pin assembly may be hydraulically actuated. The support pins may be
hydraulically actuated. The support pin assembly may comprise actuators which may
actuate the support pins. Each support pin of the support pin assembly may be provided
with a respective support pin actuator. Preferably, the support pin assembly comprises a
pair of support pins and a pair of support pin actuators. A support pin actuator may be
connected to a support pin. A support pin actuator may also be connected to a hydraulic
control system of the apparatus. A support pin actuator may be connected to the hydraulic
control system via a manifold. The support pin actuators and/or the hydraulic control
system may be connected to the pressure transmission path. The hydraulic control system
may be part of the pressure transmission path, or vice versa.
Hydraulic extension lines and hydraulic retraction lines may be provided between a support pin and the hydraulic control system and may provide hydraulic actuation to extend the support pins and hydraulic actuation to retract the support pins, respectively. Backup retraction lines may also be provided, which may provide hydraulic actuation to retract the support pins and release the apparatus from the inner tubular in the event of failure of the primary system.

The apparatus may further comprise at least one centraliser assembly. The centraliser assembly may facilitate installation of the apparatus concentrically within the inner tubular such that, during operation of the apparatus to form a connection between the inner tubular and the caisson, a circumferentially uniform pressure may be applied by the apparatus to the inner tubular.

The apparatus may comprise more than one centraliser assembly. Preferably, the apparatus comprises two centraliser assemblies: an upper centraliser assembly and a lower centraliser assembly, which may be installed axially above and below the seal arrangement, outward of the seals.

The centraliser assembly may be formed from a substantially cylindrical body portion, which may be of similar dimensions to the retaining ring. Preferably, a retaining ring and a centraliser assembly have the same or substantially the same outer diameter when a centraliser assembly is not activated.

The centraliser assembly may comprise a plurality of centraliser members. Preferably, each centraliser assembly comprises three centraliser members. Each centraliser member may be arranged with its longitudinal axis perpendicular to that of the apparatus. Where three centraliser members are provided, they may be arranged with an azimuth angle of 120 degrees between them.

The centraliser assembly may have a retracted condition, in which the centraliser members may be retracted into the body of the centraliser assembly such that they do not extend radially outwards past the outer diameter of the body. Preferably, the centraliser members are flush with the outer diameter of the body of the centraliser assembly when in their retracted condition.
Each centraliser member may be provided with a pad on its outer end. The outer surface of a pad may define a curved plane around the longitudinal axis of the apparatus. A pad may define a part-cylindrical outer surface. The part-cylindrical outer surface of a pad may correspond to the substantially cylindrical outer surface of the body of the centraliser assembly. The body of the centraliser assembly may comprise recesses around its outer circumference to accommodate the pads of the centraliser members when in their retracted condition, such that the outer surface of the body of the centraliser assembly and the outer surfaces of the pads of the centraliser members define a substantially flush circumferential outer surface.

The centraliser assembly may also have an extended condition, in which the centraliser members may extend radially outwards from the apparatus. In the extended condition, one or more of the centraliser members may be brought into contact with the inner surface of the inner tubular. In an extended condition, one or more of the outer surfaces of the pads of the centraliser members may be brought into contact with the inner surface of the inner tubular. In their extended condition, each of the centraliser members may be extended by the same distance, such that the longitudinal axis of the apparatus may be brought substantially into line with that of the inner tubular and/or such that a substantially uniform annular gap exists between the apparatus and the inner tubular. Alternatively, or in addition, each of the centraliser members may be extended by the same distance, such that the mandrel of the apparatus is separated from the inner tubular by at least a minimum stand-off distance around its circumference. The apparatus may not be separated from the inner tubular by a uniform distance around its circumference.

The centraliser assembly may be hydraulically actuated. The centraliser members may be hydraulically actuated. The centraliser members may be hydraulically actuated by the same pressurised fluid which pressurises the annular volume. The centraliser assembly and/or the centraliser members may be connected to the pressure transmission path. Preferably, the centraliser members of the centraliser assembly are connected to the pressure transmission path via an auxiliary fluid transmission path.

The centraliser members may be hydraulically actuated at a lower pressure than that which is required to expand the inner tubular. The centraliser assembly may be actuated to expand into its extended condition before the inner tubular begins to expand, upon delivery of the pressurised fluid.
The centraliser members may be retractable. The centraliser members may be retracted into their retracted condition when pressure is no longer provided by the pressurised fluid. The centraliser members may be retracted into their retracted condition when the pressurised fluid is removed or drained from the apparatus.

The apparatus may be configured to form a swaged connection between the inner tubular and the caisson.

The apparatus is preferably configured to pressurise the annular volume and thereby expand the inner tubular in a radial direction and into contact with the caisson, wherein a force from the expanded inner tubular on the caisson deforms the caisson. Preferably, the outer surface of the inner tubular is deformed. The inner surface of the caisson may be deformed, or the inner and outer surfaces of the caisson may be deformed.

The apparatus may be configured to form a shoulder in the inner tubular and/or caisson. As intended herein, a "shoulder" may be any radially extending portion of a surface of the inner tubular or caisson, disposed between two substantially longitudinally extending portions of the surface of the inner tubular or caisson respectively. A shoulder need not have a surface be oriented in a plane perpendicular to the longitudinal axis of the inner tubular or the caisson, and may for example be a gradual transition from a first substantially longitudinally extending portion at a first notional diameter, and a second substantially longitudinally extending at a second notional diameter.

Preferably, the apparatus is configured to form a shoulder in the inner tubular and the caisson. The shoulder may be formed in the inner and outer surfaces of the inner tubular, and may be formed in the inner surface of the caisson. In addition, the shoulder may be formed in the outer surface of the caisson.

Where a shoulder is formed, the shoulder may extend circumferentially around the inner tubular and/or caisson.

According to a second aspect of the invention, there is provided a method of forming a connection between an inner tubular and a caisson of an offshore structure comprising:
providing an apparatus comprising a mandrel, a seal arrangement disposed on the
mandrel and configured to create a seal between the mandrel and an inner surface of the
inner tubular in which the apparatus is located, wherein the seal arrangement comprises
first and second cup seals, axially separated on the mandrel;
delivering a pressurised fluid to an annular volume between the mandrel and the inner
tubular in use;
pressurising the annular volume and thereby expanding the inner tubular in a radial
direction and into contact with the caisson to form a connection between the inner tubular
and the caisson.

The method may comprise providing the apparatus with a bracket at its upper end and/or
at its lower end to assist with the lifting, manoeuvring and installation of the apparatus.

Prior to operation of the apparatus the method may comprise inserting the inner tubular
substantially concentrically within the caisson. The inner tubular may be supported at the
top of the caisson.

The method may comprise locating the apparatus at the caisson location, such that it may
be vertically-oriented above the caisson and the inner tubular inserted therein.

With the apparatus in place, vertically disposed over the caisson, a control umbilical may
be connected to the apparatus to perform pre-operation checks of the functional
components of the apparatus.

With the apparatus in place, vertically disposed over the caisson and the inner tubular
inserted therein, the method may comprise moving the inner tubular upwards, such that it
moves over the apparatus to sit concentrically around the apparatus.

The apparatus may further comprise a support pin assembly at its lower end, which may
comprise support pins which are operable to extend radially outwards from the apparatus
in an extended condition and/or to be retracted into the apparatus in a retracted condition.

The inner tubular may comprise slots, apertures and/or recesses which correspond to the
size, shape and location of the support pins such that the support pins may extend into the
slots, apertures and/or recesses in the inner tubular when in their extended condition.
The inner tubular may be raised until the slots, apertures and/or recesses are at a position in which they align with the support pins of the apparatus. The method may comprise hydraulically actuating the support pins to extend radially outwards into the slots, apertures and/or recesses in the inner tubular, such that they may bear the load of the inner tubular, and any other loads associated with the inner tubular.

The method may comprise lowering the apparatus, with the inner tubular supported thereon by the support pin assembly, towards the caisson. The apparatus may be lowered until the bottom of the apparatus reaches the top of the caisson.

The apparatus may comprise a fluid delivery system configured to be coupled to a source of pressurised fluid. The fluid delivery system may comprise a pressure transmission path which enables a pressurised fluid to be delivered to the annular volume. The fluid delivery system may further comprise: a fluid fill valve, vent valves, a fluid drain path comprising a fluid drain valve, a flow meter for measuring the volume of fluid flowing through the system, and air bleed valves.

The annular volume may be defined between the mandrel, the inner tubular and the first and second cup seals.

The method may comprise filling the annular volume between the first and second cup seals with low pressure fluid. The fluid may be water. The low pressure fluid with which the annular volume is filled may not be sufficient to begin expansion of the inner tubular.

The method may comprise lowering the apparatus, with the inner tubular supported thereon, to a pre-determined depth within the caisson, such that a caisson defect may be aligned with a desired position of the inner tubular. The method may comprise aligning the caisson defect with a mid-position of the inner tubular.

The method may then comprise operating the apparatus to form a connection between the inner tubular and the caisson. The connection may be a swaged connection.

To form the connection, the method may further comprise operating a high pressure pump to pump water into the annular volume via the pressure transmission path until "swaging
pressure" is reached within the annular volume. Swaging pressure is the pressure required
to make the inner tubular react by deforming and expanding into a swaged position.

The apparatus may further comprise a centraliser assembly which may comprise
hydraulically actuated centraliser members. The centraliser assembly may have a
retracted condition, in which the centraliser members may be retracted into the body of the
centraliser assembly such that they do not extend radially outwards past the outer
diameter of the body, and an extended condition, in which the centraliser members extend
radially outwards from the apparatus and into contact with the inner surface of the inner
tubular. In their extended condition, each of the centraliser members are extended by the
same distance, such that the longitudinal axis of the apparatus is brought substantially into
line with that of the inner tubular.

The centraliser assembly may function to centralise the apparatus within the inner tubular
such that, during operation of the apparatus to form a connection between the inner
tubular and the caisson, a uniform pressure is applied by the apparatus. Preferably, the
apparatus is provided with two centraliser assemblies: an upper centraliser assembly and
a lower centraliser assembly, which are located outwith the annular volume, axially above
and below the seal arrangement.

The centraliser assembly may be hydraulically actuated by the same fluid which is used to
pressurise the annular volume. The centraliser assembly and/or the centraliser members
may be connected to the pressure transmission path.

The centraliser assembly may be actuated at a lower pressure than that which is required
to expand the inner tubular (i.e. the swaging pressure). Preferably, the centraliser
assembly is actuated to expand into its extended condition before the inner tubular begins
to expand.

Upon the initial filling of the annular volume with low pressure water, the centraliser
members may be actuated by the low pressure water to move outwards towards the inner
tubular.

Upon subsequent operation of the high pressure pump, the centraliser members of the
centraliser assembly may be actuated to reach their fully expanded condition.
The method may comprise continuing to pump water using the high pressure pump such that the seals may be energised by the water to form a seal between the apparatus and the inner surface of the inner tubular. The inner tubular may react to the pressure in the annular volume and may be deformed. The inner tubular may be deformed into an expanded position in contact with the caisson. With continued application of pressure using the high pressure pump, the caisson may also be expanded and deformed into an expanded diameter. A swaged connection may be formed between the inner tubular and the caisson.

With the inner tubular swaged in position, residual pressure within the apparatus and/or the annular volume may be released. The centraliser members of the centraliser assembly may be retractable, and may be retracted into their retracted condition when pressure is no longer provided by the pressurised fluid (i.e. when the pressurised fluid is removed or drained from the apparatus). Therefore, release of the residual pressure may also retract the centraliser members of the centraliser assembly.

After the connection has been formed, the method may comprise retracting the support pins from the inner tubular by hydraulic actuation, to release the apparatus from the inner tubular, which is now held in place in the caisson.

The method may comprise raising or lowering the apparatus within the inner tubular to repeat the process of forming a connection, such that the inner tubular and the caisson are connected to one another at various locations. The method may comprise using the apparatus to form more than one swaged connection between the inner tubular and the caisson.

The method may comprise forming a swaged connection above the caisson defect and forming a swaged connection below the caisson defect.

Embodiments of the second aspect of the invention may include one or more features of the first aspect of the invention or its embodiments, or vice versa.
According to a third aspect of the invention, there is provided an apparatus for forming a connection between an inner tubular and a caisson of an offshore structure, the apparatus comprising:

- a mandrel;
- a seal arrangement disposed on the mandrel and configured to create a seal between the mandrel and an inner surface of the inner tubular in which the apparatus is located;
- wherein the apparatus is configured to pressurise an annular volume defined between the seal arrangement and the inner surface of the inner tubular, and thereby expand the inner tubular in a radial direction and into contact with the caisson to form a connection between the inner tubular and the caisson;
- wherein the apparatus is configured to form a shoulder in the inner tubular and/or caisson.

The shoulder may extend circumferentially around the inner tubular and/or caisson.

Embodiments of the third aspect of the invention may include one or more features of the first or second aspects of the invention or their embodiments, or vice versa.

According to a fourth aspect of the invention, there is provided a method of forming a connection between an inner tubular and a caisson of an offshore structure comprising:

- providing an apparatus comprising a mandrel, a seal arrangement disposed on the mandrel and configured to create a seal between the mandrel and an inner surface of the inner tubular in which the apparatus is located;
- delivering a pressurised fluid to an annular volume between the mandrel and the inner tubular in use;
- pressurising the annular volume and thereby expanding the inner tubular in a radial direction and into contact with the caisson to form a connection between the inner tubular and the caisson; and
- forming a shoulder in the inner tubular and/or caisson.

Embodiments of the fourth aspect of the invention may include one or more features of the first, second or third aspects of the invention or their embodiments, or vice versa.

According to a fifth aspect of the invention, there is provided an apparatus for forming a connection between an inner tubular and an outer tubular, the apparatus comprising:

- a mandrel;
a seal arrangement disposed on the mandrel and configured to create a seal between the
tubular and defined between the
mandrel and an inner surface of the inner tubular, and thereby expand the inner
tubular in a radial direction and into contact with the outer tubular to form a connection
between the inner tubular and the outer tubular;
wherein the apparatus is configured to create a seal with the inner surface of the inner
tubular and expand the inner tubular into contact with an outer tubular having an outer
diameter greater than 18 inches (457.2mm).

The apparatus may be configured to create a seal with the inner surface of the inner
tubular and expand the inner tubular into contact with an outer tubular having an outer
diameter greater than 20 inches (508mm).

The apparatus may be configured to create a seal with the inner surface of the inner
tubular and expand the inner tubular into contact with an outer tubular having an outer
diameter in a range of 18 inches (457.2mm) to 40 inches (1016mm).

The outer tubular may be a caisson of an offshore structure. The caisson may be a steel
caisson, and/or may for example be a 20 inch (508mm) outer diameter caisson, a 26 inch
(660.4mm) outer diameter caisson, or a 36 inch (914.4mm) outer diameter caisson.

The caisson may have a wall thickness greater than 15mm, and may have a wall thickness
in the range of 15mm to 40mm.

Preferably, the apparatus is configured to expand an inner tubular that does not require
substantial wall thickness variations over an operative portion of the inner tubular.

The inner tubular may have a wall thickness in the range of 15mm to 20mm, and may have
a wall thickness of approximately 15mm. The inner tubular may be a liner. The inner
tubular may be of substantially uniform thickness.

The shoulder may extend circumferentially around the inner tubular and/or caisson.

Embellishments of the fifth aspect of the invention may include one or more features of the
first or second aspects of the invention or their embodiments, or vice versa.
According to a sixth aspect of the invention, there is provided a method of forming a connection between an inner tubular and an outer tubular of an offshore structure comprising:

- providing an apparatus comprising a mandrel, a seal arrangement disposed on the mandrel and configured to create a seal between the mandrel and an inner surface of the inner tubular in which the apparatus is located;
- delivering a pressurised fluid to an annular volume between the mandrel and the inner tubular in use;
- pressurising the annular volume and thereby expanding the inner tubular in a radial direction and into contact with the outer tubular to form a connection between the inner tubular and the outer tubular;
- wherein the outer tubular has an outer diameter greater than 18 inches (457.2mm).

Embodiments of the sixth aspect of the invention may include one or more features of the first to fifth aspects of the invention or their embodiments, or vice versa.

According to a seventh aspect of the invention, there is provided an apparatus for forming a connection between an inner tubular and a caisson of an offshore structure, the apparatus comprising:

- a mandrel;
- a seal arrangement disposed on the mandrel and configured to create a seal between the mandrel and an inner surface of the inner tubular in which the apparatus is located, wherein an annular volume is defined between the seal arrangement and the inner surface of the inner tubular in use;
- a centralising arrangement configured to centralise the apparatus within the inner tubular; and
- a pressure transmission path for delivering a pressurised fluid to the annular volume; wherein the apparatus is configured to pressurise the annular volume and thereby expand the inner tubular in a radial direction and into contact with the caisson to form a connection between the inner tubular and the caisson.

Embodiments of the seventh aspect of the invention may include one or more features of the first to sixth aspects of the invention or their embodiments, or vice versa.
According to an eighth aspect of the invention, there is provided a method of forming a connection between an inner tubular and a caisson of an offshore structure comprising:

- providing an apparatus comprising a mandrel, a seal arrangement disposed on the mandrel and configured to create a seal between the mandrel and an inner surface of the inner tubular in which the apparatus is located and a centralising arrangement;
- operating the centralising arrangement to centralise the apparatus within the inner tubular;
- delivering a pressurised fluid to an annular volume between the mandrel and the inner tubular in use;
- pressurising the annular volume and thereby expanding the inner tubular in a radial direction and into contact with the caisson to form a connection between the inner tubular and the caisson.

Embodiments of the eighth aspect of the invention may include one or more features of the first to seventh aspects of the invention or their embodiments, or vice versa.

**Brief Description of the Drawings**

There will now be described, by way of example only, an embodiment of the invention with reference to the following drawings, of which:

- Figure 1A is an asymmetric view of an apparatus according to an embodiment of the invention;
- Figure 1B is a longitudinal section view through the apparatus of Figure 1A;
- Figure 2 is a sectional view through a seal arrangement in accordance an embodiment of the invention;
- Figures 3 to 8 show schematically sequential steps for a method of use of the apparatus of Figure 1A in a caisson repair operation;
- Figure 9 is an enlarged view of a retention pin mechanism of the apparatus of Figure 1A engaged with a liner; and
- Figure 10 is a plan view of a retention pin arrangement according to an embodiment of the invention.
Figures 11A and 11B are asymmetric and longitudinal sectional views of an apparatus according to an embodiment of the invention;

Figures 12A to 12C are prospective, plan and sectional views of a centraliser assembly of the apparatus of Figures 11A and 11B;

Figure 13 is a longitudinal sectional view of the apparatus of Figures 11A and 11B within a liner; and

Figures 14A, 14B and 14C are part-section plan views of showing the gradual expansion of the centraliser assembly of the apparatus of Figures 11A and 11B.
Description of Preferred Embodiments

Referring firstly to Figures 1A, 1B and 2, there is shown an apparatus in accordance with an embodiment of the invention. The apparatus is a swaging tool for a caisson repair operation, generally depicted at 10. The tool comprises a mandrel 12, which is generally cylindrical in form having a first upper end and second lower end. A longitudinal axis of the mandrel defines the longitudinal axis of the tool.

An upper end of the tool is provided with a lift bracket 14, and a lower end of the tool is provided with a guide bracket 16 and guide cone 18. Accommodated within the guide bracket is a support pin assembly 20, which will be described in more detail below.

The tool comprises an upper seal retaining ring 22a and a lower seal retaining ring 22b, disposed respectively between an upper seal assembly 24a and the lift bracket, and a lower seal assembly 24b and the guide bracket. The seal assemblies (together 24) contact an outer surface of the mandrel, and define the outermost diameter of the tool.

An annular volume 25 is formed between the upper and lower seal assemblies, the outer surface of the mandrel, and the inner surface of a liner into which the tool is located in use. The tool also comprises a fluid delivery system configured to be coupled to a source of pressurised fluid. The fluid delivery system comprises a pressure transmission path which enables a pressurised fluid to be delivered to the annular volume 25, a water fill valve (not shown), vent valves, a fluid drain path comprising a fluid drain valve (neither shown), a flow meter for measuring the volume of fluid flowing through the system, and air bleed valves.

In this example, the seal assemblies 24 are upper and lower cup seals, described in more detail with reference to Figure 2. The seal assembly 24 comprises a cup member 26 formed from a relatively soft, flexible elastomeric material. The cup member defines an open end of the seal assembly. An inner surface of the cup member is substantially cylindrical at the open end. An outer surface of the cup member is tapered towards its open end to define a generally conical shape between its maximum outer diameter and the open end of the seal.
The cup member 26 also comprises a neck portion 27, which is substantially cylindrical and is of reduced inner diameter and reduced outer diameter relative to the maximum outer diameter of the cup member. The neck portion 27 is disposed within a seal retaining ring 30, formed from a metal such as steel. The seal retaining ring 30 comprises a generally cylindrical body which partially surrounds the neck portion of the cup member. An end of the seal retaining ring, disposed axially away from the open end of the cup seal, is formed with a reduced inner diameter for axial engagement with a corresponding recess on the mandrel. A groove 32 is provided for accommodating an o-ring seal between the seal retaining ring and the mandrel.

The seal assembly 24 also comprises an anti-extrusion member 28, which is substantially annular in form and partially surrounds the cup member 26. The anti-extrusion member extends from the seal support ring towards the open end of the cup. An inner surface of the anti-extrusion member 28 abuts an outer surface of the cup member, and is substantially conical in form, opening towards the open end of the seal, and corresponding to a conical outer profile of the cup member between the neck portion 27 and the maximum outer diameter of the cup member.

This arrangement is beneficial as the anti-extrusion members are less susceptible to flow under pressure than the cup members. The anti-extrusion members therefore reduce or prevent the material of the cup members from flowing axially outwards between the liner and the components of the swage tool, and instead influence the material of the cup members to move radially outwards against the liner, when pressurised. The provision of the anti-extrusion members therefore improves the effectiveness of the seal between the cup members and the inner tubular.

The anti-extrusion member is formed from a relatively hard, flexible elastomeric material. In this embodiment, the cup member is formed from nitrile butadiene rubber (NBR) with hardness 80 on the Shore A hardness scale. The anti-extrusion member is formed from a nitrile butadiene rubber (NBR) with hardness 90 on the Shore A hardness scale. It will be appreciated that alternative materials and/or hardness values may be used in other aspects of the invention. Preferred embodiments use a material in the anti-extrusion member which is relatively hard compared with the material of the cup member. The anti-extrusion portion will therefore be less susceptible to flow under pressure and will improve, the effectiveness of the seal.
Embedded into the anti-extrusion member is a spring in the form of a helical garter spring 40, which extends circumferentially around the annular anti-extrusion member, and therefore around the cup member of the seal arrangement. Optionally, the spring has a core of harder anti-extrusion material, to reduce the risk of the cup material from flowing into and within the spring.

The spring may function to improve the seal which is created by the cup seals in use, as when the cup members are pressurised, the spring will be forced radially outwards against the liner to further improve the seal between the cup seals and the liner.

The seal arrangement of this embodiment comprises a cup member which is selectively bonded to at least one of the spring, the anti-extrusion member, and the seal retaining member to permit relative movement at contact areas between the components of the seal. The cup member is securely bonded by an adhesive at the base of the cup member where it abuts the seal retaining ring, and at the edge of the anti-extrusion member 28 which is axially furthest from the spring. Thus the majority of the contact between the anti-extrusion member 28 and the cup member is unbonded.

In use, the open end of the cup member is inflated by an increase in pressure in the interior of the cup, and the cup member is expanded into contact with the liner, thereby preventing flow of fluid past the device cup member. As pressure within the cup member increases, the spring is pushed outwards, and the spring moves outward and downward into contact with the liner. This improves the seal created by the device, while the anti-extrusion member is also forced into contact with the liner, and reduces or prevents flow of the softer cup member between the liner and the support member or the spring.

The relatively large unbonded surface area of the cup member allows the cup member to inflate and stretch without being restricted unduly by the anti-extrusion member 28 or the spring, while controlling the extent of the inflation of the seal. The double layer construction allows the cup member to be formed from a thinner and/or softer material, which enables it to respond to relatively low pressures. On release of fluid pressure the resilience of the cup member in combination with the spring return the seal to its original shape.
The sealing arrangement of this embodiment is selected to be effective in sealing the inner surface of typical liner dimensions used in caisson swaging applications.

In this embodiment, the outer diameter of the seal arrangement is approximately 23 inches (584mm) and is configured to be operable to form a swaged connection of a liner into a 26 inch outer diameter caisson. A typical space between the outer diameter of the liner and the inner diameter of the caisson is approximately 15mm, and the liner will typically have a uniform thickness of approximately 15mm.

A typical expansion of the caisson is approximately two per cent (2%) of the outer diameter. A consequence that the inner liner is required to expand over a greater range, and internal seals are required to maintain a seal over the entirety of the expansion range. This is in contrast to downhole applications, in which the outer tubular is not required to expand, and which may rely on conventional seal arrangements. For example, the tool of US 2004/0031615 is designed to expand a cladding into casing downhole. In typical downhole arrangements, casing is surrounded by cement and so it may be undesirable, and in fact it may cause damage to the surrounding cement, to expand the outer tubular.

Conventional seals, for example the smaller diameter seals used in downhole tools such as that described in US 2004/0031615, suffer from a number of disadvantages. In particular, they tend to be made of relatively thick rubber or other elastomer and require a small gap between the cup and a bore wall. If the gap between the cup and bore is increased, the pressure the cup will hold drops considerably and therefore not suitable for the repair of caissons. For internal swaging in caisson repair applications, it is necessary to expand both the liner and caisson to a point of permanent deformation in order to provide a method of liner retention. It has been necessary to utilise a seal that has high expansion properties. US 2005/0098313 describes a seal for downhole applications, with a similar construction to the large diameter seals used in embodiments of the present invention.

A method of use of the swaging tool 10 in a caisson repair operation will now be described with particular reference to Figures 3 to 8. Figure 3 shows a caisson 101 of a platform 100. Prior to deploying the swaging tool 10, a caisson repair liner assembly 102 formed from an upper liner section 102a, a middle liner section 102b, and a lower liner section 1-2c, is installed within the caisson 101. The liner assembly 102 is supported at the top of
the caisson by support brackets 104. A transit frame 130 initially containing the swage tool 10 is located at a suitable location adjacent to the top of the caisson, and within an area accessible by installation lifting rigging. The swage tool is removed from the transit frame cover by attaching a main lift line 106 to the lift bracket 14 at the upper end of the swage tool, and an auxiliary lift line (not shown) to the guide bracket at the lower end of the swage tool. The swage tool is lifted horizontally out of the transit frame, and a cross haul of the tool towards the caisson location is carried out whilst simultaneously upending the tool so that it is vertically-oriented above the caisson. With the swage tool fully upended and vertically disposed, the auxiliary lift line is removed from the guide bracket and the tool is positioned directly over the top of the caisson with the repair liner assembly already suspended. A control umbilical is connected to the swage tool and pre-operation checks of the functional components of the swage tool are performed.

With the swage tool supported on the main lift line 106, liner lift lines 108 are connected to the liner support brackets connected to the top of the liner assembly, and the liner is raised slowly up over the swage tool, as shown in Figure 4. The liner is raised until the slots 110 in the upper liner section 102a align with the liner support pins 141 on the swage tool. The support pins are hydraulically actuated to extend radially outwards into the slots on the liner, to a position which the support pins can bear the load of the liner assembly (Figure 9). The liner lift lines are relaxed so that the liner assembly is supported on the swage tool liner support pins.

The main lift line 106 is then used to lower the tool, complete with the liner assembly, to the floor level. With the air bleed valve open, the annular volume between the seal assemblies and the liner is filled with low pressure water. When the annular volume is full with low pressure water, the air bleed valve is closed. The liner lift lines can then be removed and the liner support brackets are removed from the liner assembly.

The swage tool 10, complete with the liner assembly 102, is then lowered on the main lift line 106 to a pre-determined depth, such that a caisson defect 120 is aligned with a mid-position of a middle section of the liner assembly, as shown in Figure 5. With the liner assembly at the correct location, the main lift line is secured in position.

The swage tool may then be operated to form a swaged connection of an upper liner section in the caisson: an air bleed valve on the top side control panel is opened, and the
water fill valve is opened to enable the system to be filled with low pressure water. The air bleed valve is closed when the system is full.

Using a high pressure pump, water is pumped into the annular space via the pressure transmission path until swaging pressure is reached. The seal assemblies 24 are energised and form a seal between the swage tool and the inner surface of the liner, as depicted in Figure 6. The liner section reacts to the pressure in the annular volume, and is deformed and swaged into an expanded position in contact with the caisson. With continued application of pressure, the caisson is expanded and deformed to an expanded diameter. With the liner section swaged in position, the vent valves are opened to release residual pressure.

The upper liner section 102a is now swaged in position and supported in the caisson. The liner support pins are retracted by hydraulic actuation, to release the swage tool from the liner. Hydraulic actuation of the swage pins to a retracted position is preferred over alternative techniques such as shear pins, as the forces required to shear the pins may result in a hazardous acceleration of the swage tool, and/or in some cases may have an adverse effect on an incompletely formed connection between the liner and the caisson.

Figure 10 shows the liner support pin assembly 20 in more detail. The assembly 20 comprises a pair of support pin actuators 140a, 140b, connected to respective support pins 141a, 141b. The actuators are coupled to a hydraulic control system via a manifold 145, and are provided with extension lines 142a, 142b which provide hydraulic actuation to extend the support pins, and retraction lines 143a, 143b which provide hydraulic actuation to retract the support pins. Redundancy is provided by backup retraction lines 144a, 144b, which provide hydraulic actuation to retract the support pins and release the tool from the liner assembly in the event of failure of the primary system.

The swage tool is then lowered in the liner assembly until the swage tool is positioned within a lower liner section of the liner assembly, below the caisson defect 120, as shown in Figure 7. The main lift line 106 is secured in this position.

The swage tool is now operated to form a swaged connection of the lower liner section. The air bleed valve on the top side control panel is opened, and the water fill valve is opened to top up the system with low pressure water. The air bleed valve is closed.
Using a high pressure pump, water is pumped into the annular space formed between the seal assembly, the mandrel and the inner surface of the liner section. The seals are energised and the water pressure in the annular space is increased to swaging pressure, as depicted in Figure 8. At the swaging pressure, the liner section reacts by deforming and expanding to a swaged position, in which it contacts the caisson. The caisson is deformed and expanded into an expanded condition.

During swaging, shoulders are formed in the liner and the caisson above and below the annular volume. The shoulders extend circumferentially around the liner and caisson, and provide a radially extending portion of the liner and caisson between the unexpanded liner and caisson and the deformed liner and caisson. The shoulders assist with the support of the liner in the caisson in conjunction with friction between the adjoining walls of external liner and inner caisson, and therefore the resulting connection has improved mechanical grip. The creation of a shoulder in the absence of pre-formed recesses or the use of non-uniform (thick-thin walled) liners enables relatively cheap liners to be used in the methods of the present invention.

The profile of shoulder from original caisson diameter to maximum deformed diameter has a transitional gradient that is dictated by the material properties of the liner / caisson. The pressure applied, and therefore the expansion of the seals, takes the original material of both the liner and caisson past the elastic state into the plastic state so that when pressure is removed the permanent deformation of the shoulder is in place.

The creation of the shoulder profile is facilitated by the choice of seal. The start of the shoulder profile at original caisson diameter is created at the position of the seal retainer ring area which does not move outwards during pressurisation. The finalised shoulder profile of maximum deformed diameter occurs at the seal spring location as this is the point that the liner first affected by the full hydrostatic pressure / expansion of seal.

With both upper and lower liner sections now swaged in position, the drain valve (not shown) at the lower end of the swage tool is opened to allow the water trapped between the cup seals and the swage tool to drain away, while the swage tool is raised from the liner. The main lift line is used to slowly raise the swage tool clear of the top of the caisson, where the control umbilical is disconnected. With the swage tool supported on
the main lift line, an auxiliary lift line is attached to commence the cross-hauling operation
to return the swage tool to the transit frame 130. The tool can then be washed down with
fresh water and all valves flushed to complete the operation.

Figures 11A and 11B show a preferred embodiment of the invention. The swage tool (and
its components) is substantially similar to the swage tool which has been described
throughout the foregoing description and will generally be understood from the foregoing
description. However, in this preferred embodiment of the tool, it is provided with two
centraliser assemblies 250a, 250b. The centraliser assemblies 250a, 250b are provided
between each cup seal assembly 224a, 224b and its respective seal retaining ring 222a,
222b.

The centraliser assemblies 250a, 250b are hydraulically actuated, and retractable, such
that they do not hinder axial movement of the swage tool within the liner. The centraliser
assemblies 250a, 250b are provided outwardly from each cup seal assembly 224a, 224b
such that they are out with the area of pressure application (i.e. the annular volume shown
generally at 225 which is defined between the seal assemblies 224a, 224b, the mandrel
212 and the liner (not shown)). In addition, the centraliser assemblies 250a, 250b are
actuated by the same pressurised fluid which is used to perform the swaging operation. As
such, in this embodiment the fluid delivery system comprises a pressure transmission path
which further comprises an auxiliary fluid transmission path 260 which enables the same
pressurised fluid to be concurrently delivered to the centraliser assemblies 250a, 250b as
that which is delivered to the annular volume 225.

A centraliser assembly 250 is shown in more detail, in isolation, in Figures 12A to 12C.
The centraliser assembly is made up of a cylindrical body portion and comprises three
hydraulically actuated centraliser members 252, with rectangular pads 254 on their ends,
The outer surfaces of the rectangular pads 254 are rounded, and the cylindrical body
portion 251 comprises recesses which correspond in location and shape to the pads 254
such that a flush outer surface is defined by the pads 254 and the outer surface of the
cylindrical body 251 when the centraliser members 252 are in their retracted condition.

Figure 13 shows a sectional view of the swage tool within a liner section 202, with the
centraliser assemblies in their retracted condition. With reference to the plan sectional
views of Figures 14A to 14C, actuation of the centraliser assemblies will now be described.
Figure 14A shows the centraliser assembly 250 in its fully retracted condition, Figure 14B shows the centraliser assembly 250 in its partially expanded condition, and Figure 14C shows the centraliser assembly 250 in its fully expanded condition.

In Figure 14A, the hydraulically actuated centraliser members 252 of the centraliser assembly 250 are fully retracted, such that the outer surfaces of the pads 254 are flush with the body 251 of the centraliser assembly 250. It can be seen that the centraliser members 252 comprise an assembly of pins and other additional components, such as spring 262. In its retracted state, no hydraulic fluid is present in the auxiliary fluid transmission path 260.

Figure 14B shows the centraliser assembly 250 in its partially expanded condition. In this condition, the auxiliary fluid transmission path 260 is becoming filled with hydraulic fluid (i.e. water) in the direction indicated by the arrow, simultaneously as the annular volume between the seal assemblies of the swage tool and the liner is filled with low pressure water (not shown). The water which fills the auxiliary fluid transmission path 260 and the annular volume is the same water from the same source. The force which is provided by the water in the auxiliary fluid transmission path 260 begins to overcome the force of the spring 262, to push the centraliser members 252 and thus the centraliser pads 254 outward from the body 251 of the centraliser assembly, towards the liner 202. In doing so, the water moves into the space 260a which is created by the outward movement of the centraliser members 252.

Figure 14C shows the centraliser assembly 250 in its fully expanded condition. The pads 254 expand (nearly fully) to touch, or almost touch, the liner 202 when the annular volume between the seal assemblies of the swage tool and the liner is full of the low pressure water, before operation of the high pressure pump is initiated to reach swaging pressure within the annular volume.

When the swaging operation commences, operation of the high pressure pump to pump water into the annular volume also results in the a higher pressure in the auxiliary fluid transmission path 260, such that the centraliser members 252 and pads 254 reach their maximum expanded condition, and contact the liner 202 sufficiently to centralise the swage tool therein. Full expansion of the centralisers occurs before the liner is deformed as a result of the swaging operation.
The centraliser members 252 are all only permitted to expand by a certain maximum distance. This distance corresponds to the small clearance area which exists between the swage tool and the liner. Therefore, controlling the actuation and retraction of centraliser members in applications in which only a small travel distance for the centraliser exists (i.e. between the tool and the liner) is particularly beneficial.

On completion of a swaging operation, normal draining of the swage tool results in draining of the auxiliary fluid transmission path 260. With hydraulic fluid no longer present in the transmission path 260 for the centraliser members 252, the spring 262 moves the centraliser members 252 of the centraliser assembly 250 back into their retracted condition.

Centralising the swage tool within the liner facilitates the application of a uniform pressure over the length and/or circumference of the liner, which can be challenging when using such a large tool. This is especially difficult when such a large-scale application, such as that described herein in relation to caissons, is combined with the increased pressure requirements and common inconsistencies and inaccuracies associated with the thickness and ovality of rolled tubulars (such as liners).

It is therefore important that pivoting of the swage tool about its longitudinal axis during swaging is reduced, not only to ensure that the pressure which is applied is uniform, but also to ensure that the seals are not damaged during the swaging process. For example, if the swage tool is able to pivot about its longitudinal axis during swaging, the annular clearance between the cup seal assemblies and the liner may be uneven. At points where the annular clearance gap is larger, there may not be sufficient reinforcement for the seal spring, causing the seal spring and seal to extrude through the clearance gap, thus damaging the seal.

For at least the reasons outlined above, it is beneficial to centralise the swage tool within the liner during pressure application. However, it is important that the swage tool is able to be centralised within the liner by a mechanism which does not otherwise pose an obstacle to the movement of the swage tool (for example, when the swage tool is being raised or lowered within the liner). This is of particular significance when the liner is of non-uniform cross section and/or wall thickness.
The invention in one aspect provides an apparatus and method for forming a connection between an inner tubular and a caisson of an offshore structure. The apparatus comprises a mandrel, and a seal arrangement disposed on the mandrel and configured to create a seal between the mandrel and an inner surface of an inner tubular in which the apparatus is located. The seal arrangement comprises first and second cup seals, axially separated on the mandrel, and configured to define a substantially annular volume between the mandrel and the inner tubular in use. A pressure transmission path delivers a pressurised fluid to the annular volume, and the apparatus is configured to pressurise the annular volume and thereby expand the inner tubular in a radial direction and into contact with the caisson to form a connection between the inner tubular and the caisson.

Various modifications to the above-described embodiments may be made within the scope of the invention, and the invention extends to combinations of features other than those expressly claimed herein.
Claims

1. An apparatus for forming a connection between an inner tubular and a caisson of an offshore structure, the apparatus comprising:
   a mandrel;
   a seal arrangement disposed on the mandrel and configured to create a seal between the mandrel and an inner surface of the inner tubular in which the apparatus is located;
   wherein the seal arrangement comprises first and second cup seals, axially separated on the mandrel, and configured to define a substantially annular volume between the mandrel and the inner tubular in use;
   a pressure transmission path for delivering a pressurised fluid to the substantially annular volume;
   wherein the apparatus is configured to pressurise the substantially annular volume and thereby expand the inner tubular in a radial direction and into contact with the caisson to form a connection between the inner tubular and the caisson.

2. The apparatus according to claim 1, wherein the first and second cup seals each define an open end, and are axially separated on the mandrel such that the open ends of the cup seals face towards one another.

3. The apparatus according to claim 1 or claim 2, wherein the first and/or second cup seals further comprise an anti-extrusion member which is substantially annular in form and which at least partially surrounds the outer surface of the first and/or the second cup seal.

4. The apparatus according to claim 3, wherein the anti-extrusion member of the first and/or the second cup seal is formed from a material which is harder than that of the first and/or second cup seal.

5. The apparatus according to any preceding claim, further comprising a support pin assembly operable to bear the load of the inner tubular and any additional loads associated with the inner tubular, and which comprises a plurality of support pins which are operable to extend radially outwards.
6. The apparatus according to claim 5, wherein the support pin assembly has a retracted condition, in which the support pins are retracted into the apparatus and an extended condition, in which the support pins extend radially outwards such that they engage with the inner tubular.

7. The apparatus according to claim 5 or claim 6, wherein the support pins are configured to extend into apertures in the inner tubular to engage with the inner tubular when the support pin assembly is in its extended condition.

8. The apparatus according to any of claims 5 to 7, wherein the support pin assembly is operable to bear the load of the inner tubular and any additional loads associated with the inner tubular in its extended condition.

9. The apparatus according to any of claims 5 to 8, wherein the support pin assembly is hydraulically actuated, and wherein hydraulic extension lines and hydraulic retraction lines are provided between each support pin of the plurality of support pins and a hydraulic control system to provide hydraulic actuation to extend the support pins and hydraulic actuation to retract the support pins, respectively.

10. The apparatus according to any preceding claim, further comprising at least one centraliser assembly.

11. The apparatus according to claim 10, wherein the centraliser assembly comprises a plurality of centraliser members and has a retracted condition and an extended condition in which the plurality of centraliser members extend radially outwards and into contact with the inner surface of the inner tubular such that the mandrel of the apparatus is separated from the inner tubular by at least a minimum stand-off distance around its circumference.

12. The apparatus according to claim 10 or claim 11, wherein the centraliser assembly is hydraulically actuated.

13. The apparatus according to claim 12, wherein the centraliser assembly is hydraulically actuated by the same pressurised fluid which pressurises the substantially annular volume.
14. The apparatus according to claim 12 or claim 13, wherein the centraliser assembly is connected to the pressure transmission path.

15. The apparatus according to any of claims 12 to 14, wherein the centraliser assembly is configured to be hydraulically actuated into its extended condition at a first pressure, and expansion of the inner tubular begins at a second pressure, and wherein the first pressure is lower pressure than the second pressure.

16. The apparatus according to any of claims 12 to 15, wherein the centraliser assembly is configured to be actuated into its extended condition prior to expansion of the inner tubular, upon delivery of the pressurised fluid.

17. The apparatus according to any of claims 12 to 16, wherein the centraliser assembly is configured to be actuated into its retracted condition when a sufficient pressure is no longer provided by the pressurised fluid.

18. The apparatus according to any preceding claim, wherein the apparatus is configured to expand the inner tubular in a radial direction and into contact with the caisson to form a swaged connection between the inner tubular and the caisson.

19. The apparatus according to any preceding claim, wherein the apparatus is configured to deform the inner and/or outer surfaces of the inner tubular such that the inner tubular is brought into contact with the caisson, and wherein a force from the expanded inner tubular on the caisson deforms the inner and/or outer surfaces of the caisson.

20. The apparatus according to any preceding claim, wherein the apparatus is configured to expand the inner tubular in a radial direction to form a shoulder in the inner tubular and wherein a force from the expanded inner tubular on the caisson expands and forms a shoulder in the caisson.

21. The apparatus according to any preceding claim, wherein the apparatus is configured to expand the inner tubular in a radial direction to form a shoulder in the inner and outer surfaces of the inner tubular and wherein a force from the expanded
inner tubular on the caisson expands and forms a shoulder in the inner and outer
surfaces of the caisson.

22. A method of forming a connection between an inner tubular and a caisson of an
offshore structure comprising:
providing an apparatus comprising a mandrel, a seal arrangement disposed on the
mandrel and configured to create a seal between the mandrel and an inner surface
of the inner tubular in which the apparatus is located, wherein the seal arrangement
comprises first and second cup seals, axially separated on the mandrel;
delivering a pressurised fluid to a substantially annular volume between the mandrel
and the inner tubular in use;
pressurising the substantially annular volume and thereby expanding the inner
tubular in a radial direction and into contact with the caisson to form a connection
between the inner tubular and the caisson.

23. The method according to claim 22, wherein the apparatus further comprises a
support pin assembly comprising a plurality of support pins, and wherein the method
comprises actuating the support pin assembly into an extended condition such that
the plurality of support pins extend radially outwards into apertures in the inner
tubular to engage with the inner tubular.

24. The method according to claim 23, comprising actuating the support pin assembly
into an extended condition such that the plurality of support pins extend radially
outwards into the apertures in the inner tubular, and such that the support pin
assembly bears the load of the inner tubular, and any other loads associated with the
inner tubular.

25. The method according to any of claims 22 to 24, wherein the apparatus further
comprises a fluid delivery system configured to be coupled to a source of
pressurised fluid and a pressure transmission path which enables the pressurised
fluid to be delivered to the substantially annular volume, and wherein the method
comprises filling the substantially annular volume with low pressure water.

26. The method according to any of claims 22 to 25, wherein the apparatus further
comprises a centraliser assembly which is hydraulically actuated by the same fluid
which is used to pressurise the substantially annular volume, and wherein the
method comprises actuating the centraliser assembly by delivering low pressure
water to the substantially annular volume.

27. The method according to any of claims 22 to 26, comprising lowering the apparatus,
with the inner tubular supported thereon, to a pre-determined depth within the
caisson, such that a caisson defect is aligned with a desired position of the inner
tubular.

28. The method according to any of claims 22 to 27, comprising operating a high
pressure pump to pump water into the substantially annular volume such that the first
and second cup seals are energised by the water to form a seal between the
apparatus and the inner surface of the inner tubular, and the substantially annular
volume is pressurised.

29. The method according to claim 28, wherein the inner tubular reacts to the pressure in
the substantially annular volume and is deformed into an expanded position into
contact with the caisson.

30. The method according to claim 28 or claim 29, comprising continuing the application
of pressure using the high pressure pump such that the caisson is expanded and
deformed into an expanded diameter.

31. The method according to any of claims 22 to 30, comprising forming a swaged
connection between the inner tubular and the caisson.

32. The method according to any of claims 22 to 31, wherein after the connection has
been formed between the inner tubular and the caisson, the method comprises
releasing residual pressure within the apparatus and/or the substantially annular
volume.

33. The method according to claim 32 and any of claims 26 to 31, wherein release of the
residual pressure causes the centraliser assembly to retract.

34. The method according to any of claims 23 to 33, wherein after the connection has
been formed between the inner tubular and the caisson, the method comprises
retracting the support pins from the inner tubular to release the apparatus from the
inner tubular.

35. The method according to any of claims 22 to 34, comprising raising or lowering the
apparatus within the inner tubular to repeat the process of forming a connection,
such that the inner tubular and the caisson are connected to one another at various
locations.

36. The method according to any of claims 22 to 35, comprising using the apparatus to
form more than one swaged connection between the inner tubular and the caisson.

37. The method according to claim 36, comprising forming a swaged connection above
the caisson defect and forming a swaged connection below the caisson defect.
A. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both national classification and IPC:

E21B

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols):

E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched:

Electronic database consulted during the international search (name of data base and, where practicable, search terms used):

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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Further documents are listed in the continuation of Box C.

See patent family annex.

Date of the actual completion of the international search: 4 December 2018

Name and mailing address of the ISA:
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040;
Fax: (+31-70) 340-3016

Authorized officer: Kecman, Ivan
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