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Large Diameter Flanged Connection Make-Up With Zero Reworks

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Abstract

Subsea installations of large diameter flanged connections can prove to be costly and dangerous. The use of Taper-Lok connectors for subsea make-up of tie-ins and manifold connections during the installation of the BP Bombax Pipeline Project provided safer and faster connection make-up times, damage resistance, reduction of weight and one time, leak free installation.

This paper will outline the reasoning behind the use of the Taper-Lok connection for this project and the areas of cost savings associated.

Introduction

The subsea pipeline portion of the BP Trinidad Bombax Project called for flanged connections to be used in 20-inch, 26-inch and 48-inch sizes. These were to be provided in Weld Neck, Swivel, Blind Flange and Misalignment designs. The need for ease of make-up at depths of 300 feet, in waters with limited visibility, high current loads and heavy weight considerations were driving forces in the connections to be used. Due to stringent BP policies, safety during installation was a major consideration, as well.

Discussions began in mid March of 2001 regarding the manufacturing of the required connections. Preliminary design requirements were developed and the Taper-Lok engineering phase began in early April. Taper-Lok offers a full range of product groups. All product groups have features, which are common elements, and several of the products offer additional, unique features and time saving devices.

Design Criteria and Requirements

General. Operating Conditions.

- External Hydrostatic Pressure = 300 feet water depth
- Operating Max. Seawater Ambient Temp. = +80 deg F
- Min. Blow Down Temp. = +14 deg F
- Max. Internal Operating Pressure = 1480 psig
- Hydrostatic Test Pressure = 1.5 times operating pressure
- Operating Temp. = 150 deg F

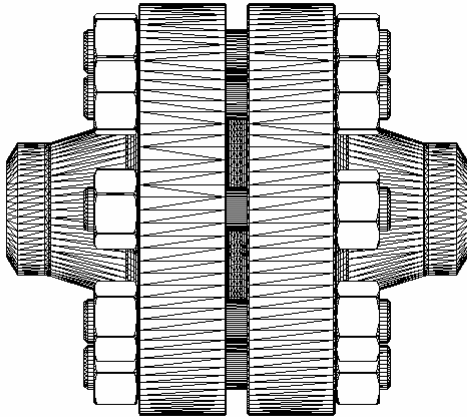
Taper-Lok was selected due to the following inherent design features:

- Sealing Integrity;
- Self Alignment During Make-Up;
- Size and Weight Reduction;
- Safety During Installation;
- Forgivingness of Sealing Surfaces;
- Misalignment Capabilities.
- Annulus Test Port Capability.
- Meets or exceeds the requirements of ASME Section VIII, Division 1 and 2, API 6A, ANSI, and MSS flange design standards.
- Self-Energized/Pressure Energized, Reusable, Seal Ring.
- Smaller/Lighter Bolts

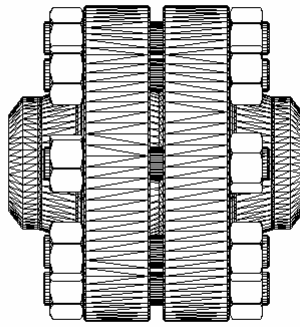
Flange Requirements.

Size	Description	Qty.
48"	Weld Neck Flanges	12
48"	Swivel Flanges	8
48"	Blind Flanges	11
26"	Weld Neck Flanges	16
26"	Swivel Flanges	11
26"	Blind Flanges	13
20"	Weld Neck Flanges	11
20"	Swivel Flanges	4
20"	Blind Flanges	7
48"	5° Misalignment Connectors	2
26"	10° Misalignment Connectors	3
Total		98
Various Sizes Studs with 2 Nuts ea.		2,700 +

Size and Weight Comparison



ANSI Flange



Taper-Lok Flange

Nominal Size	Material	REQUIRED ANSI ASSEMBLY				STUDS & NUTS		
		Equivalent Pressure (psi) ⁽¹⁾	ANSI Class ⁽⁴⁾	O.D. (in.)	Total Assembly Weight (2 Flanges, Seal Ring and Studs & Nuts) (lbs.)	Quantity	Size (in.)	Weight (lbs.) ⁽²⁾
20-Inch	A694 F65	1,734	900	33.75	2102.6	20	2.00	23.3
26-Inch	A694 F65	2,077	900	42.75	4297	20	2.75	50
48-Inch	A694 F65	2,249	900	70.25	14743.4	24	4.00	144
48-Inch (valve) ⁽³⁾	A694 F65	2,161	900	70.25	5,643 (male only)	24	4.00	144

Nominal Size	Material	EQUIVALENT TAPER-LOK ASSEMBLY					STUDS & NUTS		
		Working Pressure (psi)	Axial Force (kips)	Bending Moment (kip-ft)	O.D. (in.)	Total Assembly Weight (2 Flanges, Seal Ring and Studs & Nuts) (lbs.)	Quantity	Size (in.)	Weight (lbs.) ⁽²⁾
20-Inch	A694 F65	1480	1.0	50	27.13	775	24	1.25	5.6
26-Inch	A694 F65	1480	1.0	250	34.50	1,430	32	1.38	7.7
48-Inch	A694 F65	1480	650	1,000	59.88	6,150	36	2.25	32.6
48-Inch (valve) ⁽³⁾	A694 F65	1480	0	1,500	61.50	3,130 (male only)	36	2.25	34.2

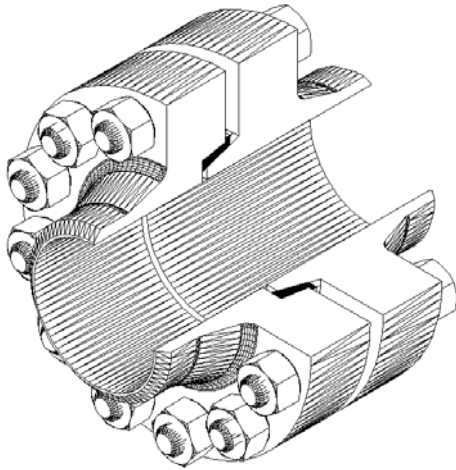
⁽¹⁾ Derived from standard equivalent pressure calculation using external axial loads and bending moments along with internal pressure.

⁽²⁾ Weight based on standard length of studs.

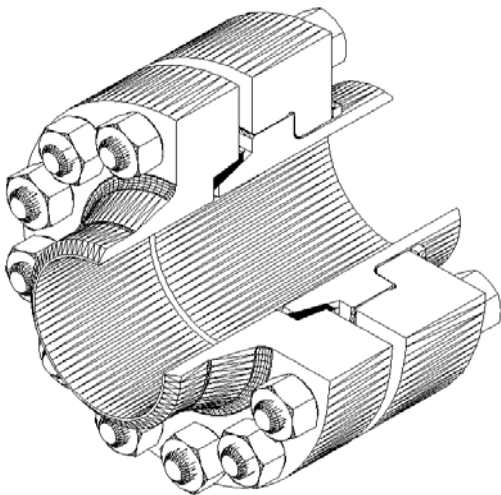
⁽³⁾ The O.D. of the 48-inch male flange that mated with the valve was increased to accommodate bolt circle of the integral flange on valve.

⁽⁴⁾ Due to external loads which would be exerted on the pipe, an increase to ANSI 900# would be required.

Weld Neck Flange Assemblies

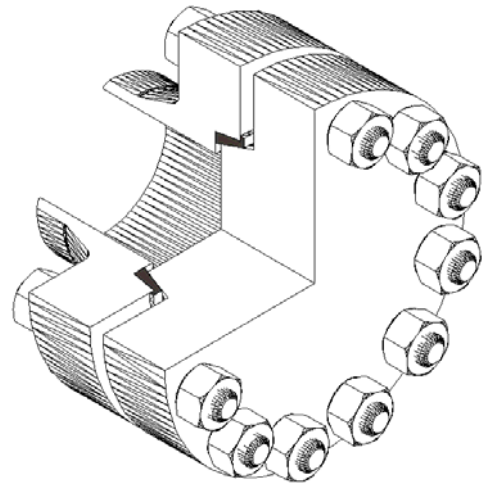


Swivel Flange Assemblies. Swivel flanges assemblies are comprised of a female weld neck flange, seal ring, male fitting, rotating ring flange, and a complete set of studs with nuts. This product encompasses all of the features of the weld neck flange plus the ability to align bolt holes with a simple rotation of the rotating ring flange. Taper-Lok swivel flange sizes 12-inch and larger are designed with bearing races, rather than a retainer ring to facilitate ease in turning during installation.



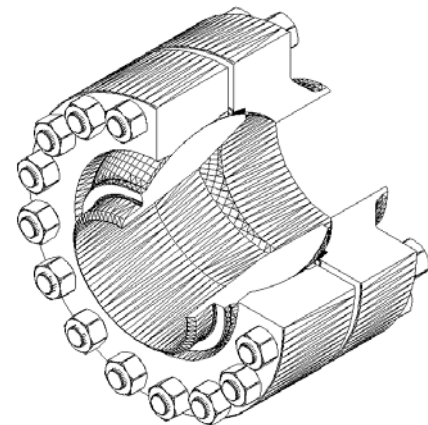
This feature is particularly important when installing subsea pipelines. When pipe is pulled across the ocean floor it has a tendency to twist (helix) and bolt holes on mating flanges in many cases does not match up. The rotating ring flange allows the diver or the ROV to reposition the bolt holes on the rotating ring flange to match those of the mating flange on the opposite pipe spool. This saves numerous hours of installation time.

Closure Assemblies. Closure assemblies consist of a male or female weld neck flange, seal ring, male or female blind, and a full set of studs and nuts.



Closure assemblies are frequently used as “ACCESS WAYS” on pressure vessels and as temporary connections on piping. Additional high use applications are “PIG” launchers and receivers. Closures assemblies are also used where internal elements need to be removed from equipment such as pumps, pressure vessels, filters, and separators.

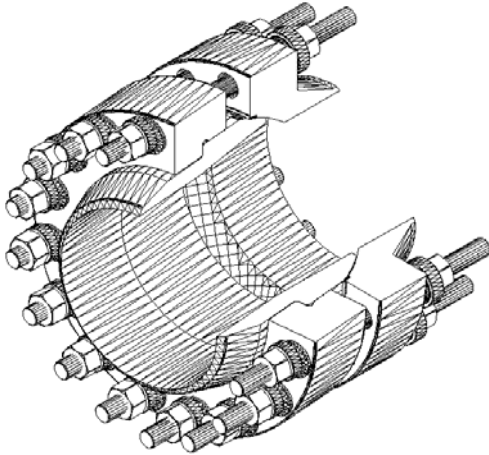
Misalignment Swivel Flanges. Misalignment swivel flanges consist of a special female weld neck flange, a spherical seal ring, annulus test port, seal ring retainers, male – ball shaped fitting, and a rotating ring flange.



26-Inch, 600#, 10° Misalignment Connector

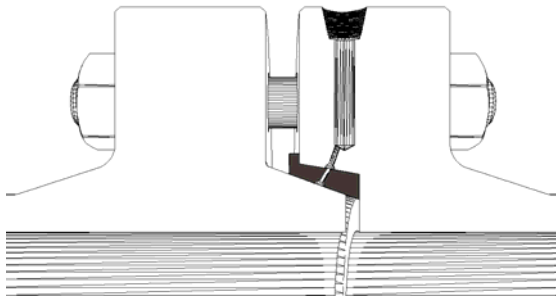
This product is specifically targeted at subsea pipeline installation and bridge connections on offshore platforms. It is very common to lay a subsea pipeline from two directions with the intention of the lay being in as straight a line as possible. However, depending on obstructions on the ocean floor and subsea contours it is sometimes impossible to have the mating pipelines terminate directly “ON AXIS”. When a less than straight on butt-up is made, a misalignment swivel

flange is used to connect the mating pipelines. Taper-Lok misalignment swivel flanges will tolerate up to 20° of axial misalignment by means of ball shaped –male sealing element and a seal ring that is contoured to match the radius of the ball fitting. Maximum misalignment requirements for the 48-inch portion of the Bombax Project called for only 5°. Designing to this misalignment decreased the size and weight of the connectors drastically. Initial designs for the 48-inch, 10° misalignment connector would have provided a total assembly weight of approximately 40,000 pounds. By reducing the amount of misalignment, the assembly weight was reduced by approximately one third.



48-Inch, 600#, 5° Misalignment Connector

Annulus Test Port. Annulus Test Ports are designed to facilitate Seal Integrity Testing at the point of manufacture and in the field, prior to and after installation is complete. The offshore industry demands that the sealing integrity of a mechanical connection be verified in the form of hydrostatic or gas testing prior to being submerged.

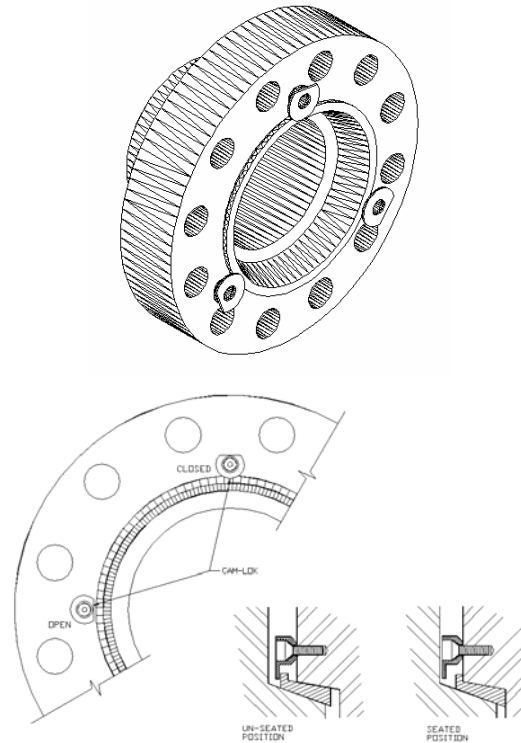


A flange connection that becomes part of a subsea pipeline, flow line, or production manifold cannot be retrieved after initial installation without extreme expense. In some cases, the connection cannot be retrieved or accessed, period. For applications such as this, it is extremely important that the seal integrity be verified at the point of manufacture and in the field.

Annulus Test Ports were provided on all Taper-Lok connectors. Shop testing was performed at the Taper-Lok Houston Facility on all misalignment connectors before delivery to the field.

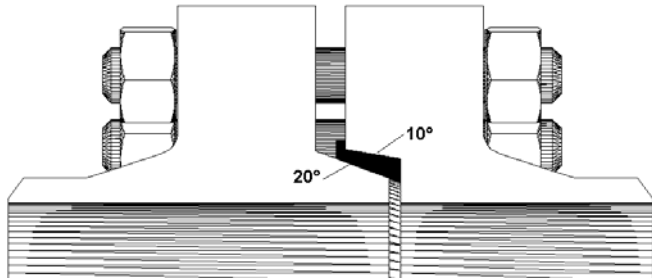
Self Alignment. Due to the conical design of the Taper-Lok female pocket and male nose, the connection self aligns during make-up. During tensioning the sealing surfaces are moved into their proper position. This feature decreases the numerous man-hours required before a connection can be made-up, reducing costs during installation.

Cam-Lok Seal Ring Retainers. Taper-Lok designed and installed a Cam-Lok Seal Ring Retainer System on all subsea connections. This capability is unique to Taper-Lok designs. By securely installing the seal ring in the female flange, a diver does not need to transport the seal ring to the ocean floor or attempt to install the seal ring subsea. Visibility can be non-existent, cold weather gear can make it difficult to handle a seal, access to the flange can be severely restricted and even under ideal conditions it is time consuming to handle a loose piece in a sub-sea environment. The seal ring can be installed on the platform or barge prior to the connection being lowered into the sea. This feature saves an enormous amount of installation and handling time by offshore personnel as well as providing for safer make-up. The seal ring is held in place keeping hands and fingers away from mating connectors.



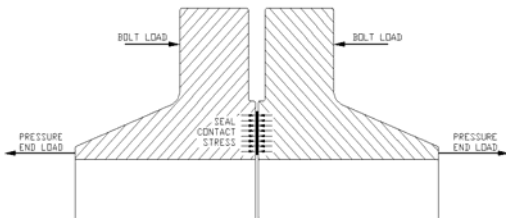
Basic Taper-Lok Technologies. Weld neck flange assemblies are comprised of a male flange, female flange, seal ring, and a complete set of studs and nuts. This product is normally sold to “PIPING” applications for topsides of offshore platforms, flow lines, production risers, manifolds, chemical plants, refineries, power generation, supercritical wet oxidation, and numerous other applications.

Taper-Lok Sealing Technology. Converging angle design of the Taper-Lok seal ring creates a wedge or “door stop” effect as internal pressures rise



Internal pressure acting on the back side of the seal drives it tighter into this sealing wedge.

Seal Loads. A standard flange has a simple flat gasket, usually made of various materials, sandwiched between the seal surfaces. The seal has to maintain a substantial contact pressure with the seal surfaces to maintain a quality seal. To do this, the bolt load must contain the pressure end load of the flange, a full operating pressure and keep the substantial contact pressure on the seal.

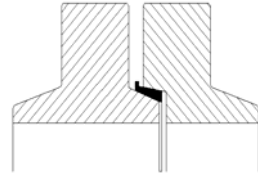


The same holds true for the various ring type gaskets that are available.

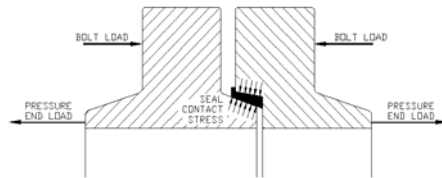
A typical Taper-Lok flange consists of a male and female bolted flange with a conical shaped seal ring. The seal surfaces of the seal ring and the mating flanges have converging tapered surfaces.



In the pre-bolted condition, the seal ring stands proud of the female flange with a gap between the lip of the seal and the face of the female flange.

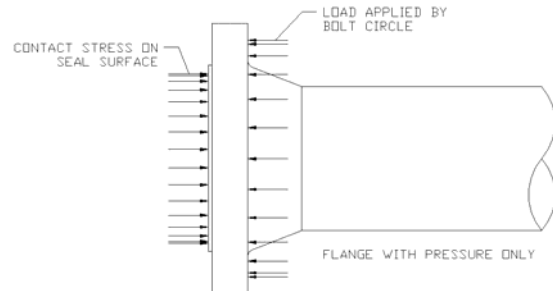


During bolt up, the converging seal surfaces are brought together like a wedge. This wedging motion forces the seal ring down the male nose and into the female pocket. The seal ring is now in hoop compression acting against the female seal surface and the male nose. Because of the shallow angles, in relation to the bolt load, the mechanical advantage translates into minimal bolt load to achieve the required contact stress on the seal surfaces. In addition to the self energizing of the seal, internal pressure from the production medium, acts against the back of the seal ring forcing it tighter into the converging seal surfaces.



Both seal surfaces slide against each other under a high contact stress. This high pressure sliding burnishes the seal surfaces removing any light imperfections. The large seal surface area reduces the chance that other imperfections will result in a leak. To protect the seal surfaces for galling, the seal ring is coated with a baked-on, moly-graphite coating. The Taper-Lok flange is designed in accordance to ASME Sec. VIII Div. 1 App. 2. The seal is modeled as a solid flat metal gasket.

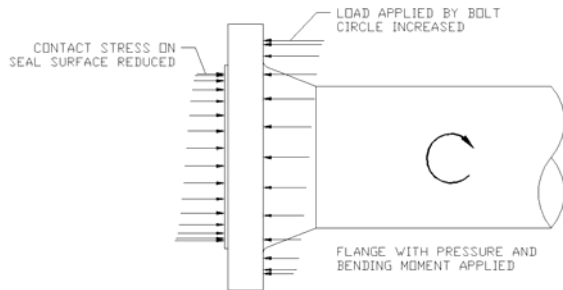
Bending and Axial Loads. A standard bolted connection in the static make-up condition has an even contact stress on seal surfaces around a gasket diameter on the face of a flange. This contact stress is maintained by a number of tensioned bolts along a bolt circle that surrounds the gasket diameter.



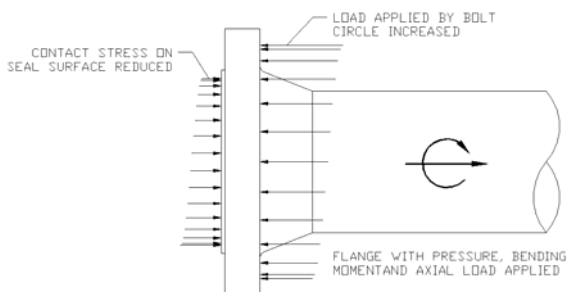
To maintain a seal the sum of the tension on all the bolts of a standard connection must equal the required gasket load plus the pressure end load acting on the gasket area. When a bending load is applied to a standard ring type flange,

the contact stress on the seal surface will shift. One side of the seal surface will experience a higher contact stress. This contact stress will taper down along the seal surface to an area 180 degrees where the contact stress is reduced. The higher contact stress area will act as a pivot point or fulcrum of the flange.

The bolts will experience a corresponding shift in tension. The bolts that are in the seal area of higher contact stress will be relaxed while the bolts on the opposite have increased tension.



With a flat face or ring type joint, as a bending load is placed on the flange, the contact stress on the seal surfaces changes from an evenly distributed load around the gasket diameter to an uneven load as shown. Add in axial loads and the contact stress on the seal surfaces is reduced even more.



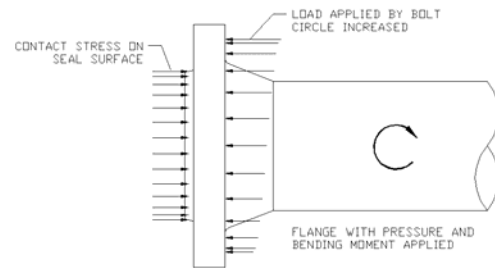
A standard Equivalent pressure equation that takes bending and axial loads into consideration is:

Pressure Equivalent,

$$Pe = P + \frac{16Mp}{\pi G^3} + \frac{4Fp}{\pi G^2}$$

Were: P = Working Pressure
 Mp = Moment acting on Pipe
 Fp = Axial Force acting on Pipe
 G = Gasket Diameter

For a Taper-Lok, bending loads are analyzed in a different manner than a standard ring type joint. Since the geometry of a Taper-Lok flange does allow for some misalignment of the flange faces and still maintain a high integrity seal, the pivot point or fulcrum of the loads are conservatively assumed to be at the center of the flange. The tension in the bolts shifts to one side as in standard connections however the contact stress on the seal remains even.



Therefore the max stress for the bolts is determined by increasing the preload by an additional amount equal to $4Mp/Gm + Fp$, to compensate for the pipeline bending moment and tensile load as follows. This increase is capped off at 50% of the bolt yield. Additional bolting area is added if the preload exceeds 50%. Although more severe than reality, this additional bolt preload always ensures that the entire seal surface is subjected to a positive bearing stress and prevents gasket separation when the pipeline loads are applied. It also ensures that flange stresses are uniform around the flange circumference. In practice, however, Taper-Lok flanges do not require this additional preload, because of the Taper-Lok pressure-energizing seal. Rather the bolts need only be preloaded to an amount equal to the pressure load acting at the gasket diameter. Generally at or below 25% of bolt yield. Analysis of the flange using the lower preload that excludes the pipeline loads, however, is somewhat complex and cannot be analyzed appropriately using simplistic calculations. In reality, some bolts experience a stress equal to that caused by the pipeline loads, as do some flange cross-sections. In order to include this effect in the analysis, it is conservative and much simpler to analyze the flange as though all bolts are additionally preloaded by the $4Mp/Gm + Fp$ amount. This additional preload is then used in the flange calculations for verification.

JP Kenny Connector Evaluation Data

JP Kenny gathered and assembled data for both ANSI and Taper-Lok flanged connections and developed a Rank Scale for final evaluation of each system. Results were as follows:

Large Diameter Flanges: Technical Evaluation

		ANSI Flange	Rank	Taper Lok	Rank
1	Flange Material ⁽¹⁾	ASTM A350 LF 6	A	ASTM A350 LF 6	A
2	Gasket Material	RTJ gasket will be made from softer material than the flange material.	C	Gasket material is same as the flange material.	A
3	Bolt Material	ASTM A193 Gr-B7	A	ASTM A193 Gr-B7	A
4	Corrosion ⁽²⁾		C	Lesser exposure to corrosion ⁽²⁾	A
5	Bolt Tension	Requires higher bolt tension to keep the RTJ gasket in contact with the gasket groove.	B	Smaller bolt tension because the pressure energized seal and less likelihood of separation due to the tapered seal surfaces.	A
6	Bolt Diameter	Code specified bolt & bolt circle diameter.	B	Size optimized to fit pressure end load of flange and bending loads.	A
7 a	Make up gap	About 3/4" for 48" flange.	A	About 1 1/4" for 48" flange.	B
7 b	Misalignment	Zero misalignment capability.	B	Some misalignment capability because of the tapered gasket design.	A
8	Bending Moment Capacity	Smaller bending moment capacity because inability to misalign w/o breach of seal.	B	Higher bending moment capacity because of ability to misalign slightly and maintain full contact of seal surface around gasket diameter.	A
9	Bolt relaxation	Possible because the gasket is plastically deformed during make-up.	B	Less likelihood of relaxation because the gasket loads remain below 90% of yield.	A
10	Design Flexibility	No flexibility because the dimensions are specified by the code.	B	Flexible design, dimensions can be changed to match the requirements.	A
11	Flange Weight	Flange size is fixed by B16.47 or SP-44.	B	Smaller and lighter than ANSI flange.	A
12	Availability of misalignment flanges	Misalignment Flanges up to 10 degrees are available.	A	Taper Lok make flanges with max. 10 deg misalignment.	A
13	Susceptibility to damage	Mating flange may hit the projected half of the RTJ gasket.	B	Male flange has a projection that may hit the female flange.	C
14	Leak Test	Requires pipeline to be pressured.	B	Seal can be tested without pipeline pressure.	A
15	Pressure energized seal	No	B	Pressure acting against seal drives seal tighter into converging tapered seal surfaces.	A
16	Made up gap	Need to check for uniform made up gap.	B	Need to check for uniform made up gap.	B
17	Effect of Check Valve Clapper Impact Loads.	Bearing stress may exceed allowable.	B	Bearing stress is within allowable.	A
	TOTALS	4 A's, 12 B's, and 2 C's		15 A's, 2 B's, and 1 C	

⁽¹⁾ Flange material was changed to ASTM A694 F65.

⁽²⁾ If Taper-Lok flanges are used, there is no galvanic corrosion problem. The ring is cut from similar/same chemistry material as the flanges, hence there is no dissimilar metal-to-metal contact between the ring and flange. If another flange design is used (such as Taper-Lok) which employs a ring material that is not low alloy steel (higher alloys such as stainless steel, or a nickel base alloy such as Inconel) there is a potential for a galvanic couple to be set up between the ring and the flange. In this scenario the ring would be the cathode and the flange would be the anode. This creates the potential for corrosion on the flange (internally) in the area around the ring. If they inlay the ring groove with the same material as the ring (Inconel 718 is very similar to 625 from an electrochemical standpoint) this will prevent the seal area from corroding which is critical. However, there will be a galvanic couple between the inlay (cathode) and the flange (anode). However the flange is large compared to the cathode (seat inlay) so the corrosion will be spread out over a large area and will be inconsequential.

There will be no galvanic corrosion externally anywhere. All the steel will be polarized to anode potentials. Internally there will only be the potential for corrosion in the water phase if there is one.

Conclusions

J.P. Kenny Engineering facilitated a team concept early in the Bombax Project, allowing equipment manufacturers, fabricators, and installation dive contractors to correspond freely during all phases of the project. This policy contributed greatly to ease of installation in the field. The decision was made to use Taper-Lok on all sub-sea tie-ins and manifold connections. Production was begun in August of 2001 and required completion by February 7, 2002. Delivery dates of all parts were met or improved.

The use of Taper-Lok connections provided tremendous cost savings for the Bombax Project. All subsea connections were made-up with Zero Leakage, the first time, negating the need

for disassembly of the connections subsea, replacement of the seal rings and remaking the connections. In normal operations, the make-up of flanged connections can require as many as 5% -10% of the connections to be re-made. Average costs of \$100,000.00/day for dive ships and make-up times of 1 hour per inch diameter can prove to be costly.

Acknowledgments

Taper-Lok Corp. would like to thank both BP and J.P. Kenny for the opportunity to work on the Bombax Project. We also extended our appreciation to CalDive, Stream-Flo Industries and Perar Valve for their assistance and teamwork, making a challenging project successful.