OTC 15275

Design Challenges of a 48-inch Pipeline Subsea Manifold

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Abstract

Initially not part of the project design, one of the most significant design challenges of the BP Bombax Pipeline Project was the design, fabrication, and installation of a 48-inch pipeline subsea manifold. The manifold is multi-purpose and meets the following project needs:

- Looping the 40-inch and 48-inch systems;
- Minimizes seabed congestion around Cassia 'B';
- Allow early production of gas from Kapok;
- Allows for isolation of any sub-system for either repair, future expansion, or testing;
- Minimized the installation activities;
- Facilitates diver access and minimizes the number of subsea tie-in's;
- Ties-in the Cassia 'B' to Kapok import and the 48-inch export pipelines;
- Provided a secure location for the Cassia 'B' pipeline ESD isolation valves;
- Facilitates crossings of the existing pipelines;
- Provide for future expansion of the gas transportation system and provision for additional field expansion.The manifold was designed:
- For a 50 year design life;
- To provide double block-and-bleed isolation of all tie-in's;
- To withstand the pipeline design loads which included seismic loading;
- To house the Cassia 'B' platform incoming and export pipeline ESD valves (26-inch fail-closed ESD ball valve and 48-inch check valve) along with the actuated control valve in the 40/48-inch pipeline loop piping;
- To accommodate the anticipated expansion needs of BP's offshore assets.

Procurement of the required 48-inch subsea valves, bends, and fittings provided numerous challenges. As a result the manifold has major components manufactured in 8 different countries.

The manifold structure was designed in accordance with API RP 2A and piping in accordance with ASME B31.8 and API RP 1111. Fabrication of the manifold took place in Trinidad and Tobago.

Introduction

In response to the increasing demand for energy in the form of natural gas, BP Trinidad and Tobago has started expanding its offshore fields and gas transportation system to supply new LNG trains at Point Fortin on the West side of Trinidad as well as the increased local domestic market. There are two projects currently underway to expand production and transportation of gas from 1.5 bscfd to 3.0 bscfd, the Kapok Project and the Bombax Project. The Kapok Project comprises a new 2.6 BCFPD production platform, Cassia 'B' that is bridge connected to the existing Cassia 'A' platform and a new drilling platform Kapok. The Bombax Pipeline Project includes 63 km of 48-inch offshore pipeline from Cassia 'B' to landfall at Rustville, on the East Coast of Trinidad. From the landfall, the pipeline extends 1.8 km onshore to the existing Beachfield slug catcher and production facility for onward transportation of gas to the various industries on the island including the LNG facilities on the West Coast. The offshore end of the 48-inch pipeline is connected to the existing 40-inch pipeline via a 20-inch subsea jumper. This jumper facilitates looping of approximately 2/3's of the existing 40-inch pipeline thereby expand the transportation system capacity.

Additional gas production to meet the growing industrial demand will be supported by a new wellhead platform located at the Kapok field along with continued development of existing fields. The Kapok platform is, linked to the Cassia 'B' production hub by a 26-inch, multi-phase pipeline, installed as part of the Bombax Pipeline Project. Due to the development schedule, the Kapok platform will be ready for production before the Cassia 'B' hub topsides is available. To allow Kapok to produce early gas, it is intended to carry out separation on Kapok with the test separator and transport liquids via a new 6-inch line to the existing 12-inch liquids. The 12-inch liquid line transports liquids to shore from BP's existing platforms originating from the Mahogany platform. Tie-in to the existing 12-inch liquid line is via a pre-existing subsea hot-tap tee. The Kapok separated gas is then transported via the 26-inch line to the subsea manifold and into the 48-inch pipeline for transportation to the Beachfield facility via an early gas jumper on the manifold. Figure 1 provides a layout of the new Bombax development and the existing pipelines.

To satisfy the requirements for the Cassia ’B’ platform safety, a check valve for the 48-inch export pipeline, and an SSIV for the incoming 26-inch line from Kapok are required., Additional the project required the installation of an actuated valve in the 20-inch line looping the 40 and 48-inch pipeline to enable isolation of the large gas inventories in these lines if needed. In light of the complexity required to meet the project requirements, it was decided to accommodate the valving and piping within a single manifold structure. Also in line with the project’s objective to maximize the use of local content, the manifold was constructed in Trinidad. Add to this individual 48-inch, 26-inch and 20-inch tie-in spools of up to 300 feet long and 270 tons, collectively Bombax presented an interesting and challenging project. This paper focuses on the design of the Cassia ‘B’ Manifold.

Design Objectives

The primary objectives of the Cassia ‘B’ Subsea Manifold design were to minimize congestion around Cassia ‘B’ platform; allow for production of Kapok gas prior to Cassia ‘B’ platform being operational; allow for looping of the 48-inch and 40-inch pipeline systems through actuated valving; allow work on any sub-system without affecting other sub-systems; and to provide a secure location for Cassia ‘B’ ESD equipment.

Secondary objectives were to facilitate the crossing of the existing 40-inch and 12-inch pipelines with 48-inch and 26-inch pipelines; provide for future field expansion; and to limit the number of heavy lifts required over the existing pipelines.

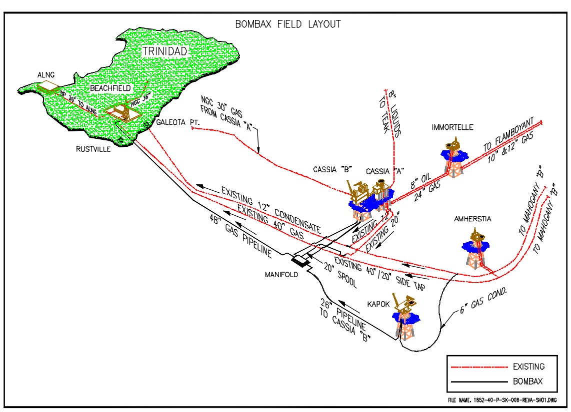

Figure 1
Bombax Field Layout

Seabed Congestion Relief

From the Bombax project Select Stage engineering the following tie-ins spools and valving were required in the vicinity of Cassia ‘B’ platform:

- A 20-inch line with isolation valving actuated from Cassia ‘B’ to tie-in the existing 40-inch gas pipeline to the 48-inch gas pipeline using the existing side-tap on the 40-inch pipeline;
- A skid mounted 48-inch check valve located in the tie-in spool between the Cassia ‘B’ riser and the export pipeline;
- A 26-inch fail closed ESD ball valve located in the tie-in spool between the Cassia ‘B’ riser and the Kapok-Cassia pipeline;
- A 48-inch x 36-inch hot-top tee for future expansion facing south.
- Capability to extend the 48-inch pipeline further offshore in the future if deeded
- Early gas jumper to connect the 26-inch Kapok-Cassia pipeline to the 48-inch pipeline

Figure 2 shows the field layout in the vicinity of Cassia ‘A’ and the future Cassia ‘B’, as well as the manifold location. The future Cassia ‘B’ platform has risers located on the south face as follows, listed from west to east:

- 1x 48-inch for tie-in to the Export Pipeline;
- 1 x 26-inch for tie-in to Kapok;
- 1 x 36-inch for future tie-in;
- 1 x 26-inch for future tie-in.

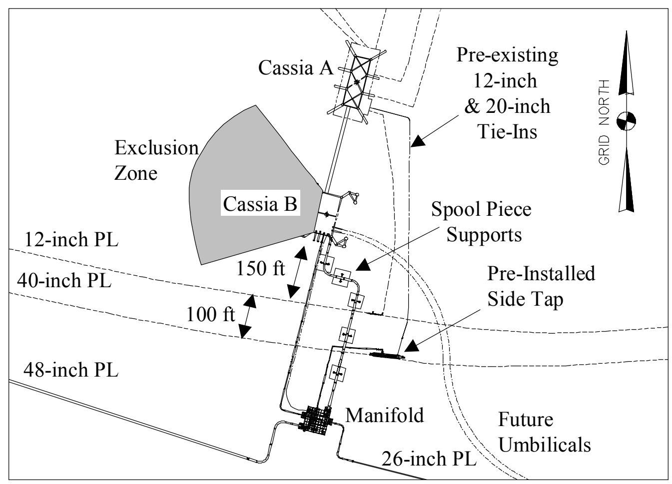

Figure 2
Cassia Platform and Vicinity

Of these the 48-inch riser and eastern most 26-inch riser are tied into the manifold. The remaining two risers are for future projects. The distance between the Cassia ‘B’ riser base and the 12-inch liquids export pipeline is 150 feet, with the 40-inch pipeline approximately 100 feet beyond that. The Kapok 26-inch export pipeline approaches from the southeast and the 48-inch gas export line approaches from the west. The area to the west of Cassia ‘B’ is an exclusion zone. A chemical injection umbilical and a power cable will be installed off the east face of Cassia ‘B’ in 2003. The route shown for these umbilicals is representative only, and is yet to be finalized.

The result is a very limited area in which to install the required equipment and tie-ins north of the 12-inch pipeline. There is ample room south of the 40-inch pipeline and crossing of the 40-inch and 12-inch pipelines with 26-inch and 48-inch pipelines at some point was required. The project team elected to locate the various valves on the south side of the existing pipelines to provide space for the future pipelines and minimize seabed congestion. This had the added benefit of eliminating the need to cross the existing pipelines during the pipelay activities. To accommodate the required valving and equipment a minimum of 7 skids were envisioned in addition to 10 tie-in/crossing spools. It became apparent that if these skids could be accommodated into a single manifold it would reduce the amount of area required considerably and maximize the possible approaches for any future lines to Cassia 'B'. Direct positive side affects of placing all the subsea equipment into a single manifold were:

- Reducing the number of heavy lifts near the exiting pipelines from 17 to 11;
- Reducing the number of subsea flange make-ups from 21 to 15;
- Allow an ROV to access the subsea valves on a single platform;
- Reduce the total installation duration and therefore exposure to weather downtime.

The single negative affect was to increase the maximum lift weight from an estimated 125 tons (skid 12, Figure 3) to 400 tons. A maximum 400-ton weight was used as project imposed upper limit to allow for a larger base of possible installation vessels.

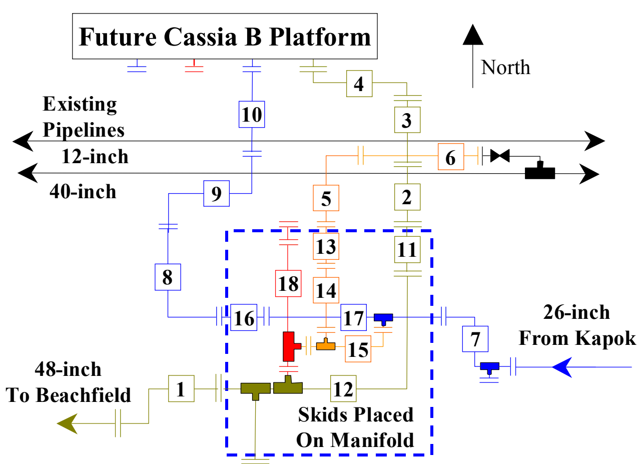

Figure 3
Valve Skids and Tie-Ins

Table 1 describes the skids and spools called out in Figure 3 and provides the approximate weights for the skids incorporated into the manifold.

Had the system been installed as a series of separate pipe spools and valve skids the system would be:

- Less flexible;
- Have incur more risk during installation, hook-up, and operation;
- Required more diver and vessel time to install;
- Required a more complex crossing system for the 48-inch pipeline;
- May have restricted the access to the southern Cassia 'B' approaches.

No.	Dia. (in)	Function	Approx. Weight* (ton)
Spools			
1 to 4	48	Beachfield to Cassia 'B' tie-in	
5 to 6	20	40-inch to 48-inch tie-in	
7 to 10	26	Kapok to Cassia 'B' tie-in	
Skids			
11	48	Cassia 'B' Isolation Check Valve	64
12	48	Double block and bleed ball valve skid, including 36-inch future hot-tap tee.	142
13	20	Actuated isolation ball valve skid. Controlled from Cassia "B".	10
14	20	Double block and bleed ball valve skid, to allow isolation valve removal for maintenance or repair.	19
15	20	Double block and bleed ball valve skid, to allow early production of Kapok gas.	17
16	26	Cassia "B' fail-shut ESD ball valve skid.	26
17	26	Double block and bleed ball valve skid, to allow ESD valve removal for maintenance or repair.	43
18	36	Double block and bleed ball valve skid, to for future tie-ins.	80

Table 1
Spool Piece and Valve Skid Descriptions

Allowing for Gas Production Prior to Cassia 'B'

There were two project objectives with regards to production of gas prior to Cassia 'B' being operational. The first was to loop the existing 40-inch system with the new 48-inch system to increase the export system capacity as required to support startup of the LNG facility expansion. The second was to allow the new Kapok platform to produce gas and export it through the 48-inch system. These two activities are referred to as First Gas and Early Gas respectively.

To achieve the First Gas a 20-inch spool piece connects the pre-existing side-tap on the 40-inch pipeline with the manifold. Gas flow is through skids 5, 6, 13, and 14 and into the 48-inch pipeline. The double block and bleed (DBB) valves on Skids 12 and 15 allow this to take place while keeping the 26-inch system and the 48-inch spools to Cassia 'B' isolated (see Figure 3). This allows the systems to be looped and commissioned before setting of the Cassia 'B' deck which is scheduled to occur after the LNG expansion is complete.

To ensure deliverability to meet the increasing gas sales requirements, it was decided to provide the ability for Kapok Early Gas since the LNG expansion is scheduled to be completed before the Cassia 'B' is commissioned. As part of the Bombax Project a 6-inch export pipeline was laid from Kapok to a tie-in on the 12-inch condensate line. This will allow export of gas coming off the Kapok test separator through the 26-inch pipeline and skids 7 and 15, while exporting the liquids through the 6-inch line. Skid 17 on the manifold provides DBB valve isolation for the 26-inch spools to Cassia 'B'.

Both of these sub-systems are intended to remain operating while Cassia 'B' topsides is installed and the riser piping tied-in.

Facilitating Pipeline Crossings – Pipe Supports

The size of the 48-inch pipeline makes installation of crossing spools a potential hazard to the existing pipelines. The spool piece pipe is coated with 5-inches of 190-lb/ft^3 concrete weight coating. This gives it a flooded unit weight of 1600 lb/ft. The total weight of the tie-in spools (2, 3 and 4 on Figure 3) is in excess of 370 tons. The 48-inch pipeline crossing is further compounded by the stiffness of the 48-inch pipe. The crossing would have to be by the use of multiple bends. Due to the requirement for intelligent pigging the minimum allowable bend radius for the 48-inch pipeline is 12 feet (3 x OD).

To facilitate the 48-inch pipeline crossings the centerline of the 48-inch pipe was placed 11 feet above the seabed in the manifold. A conventional zee-bend is used to tie in the 48-inch export pipeline into the manifold via Spool 1 (see Figure 3) and at the same time raising the elevation of the line to essentially match the riser elevation. On the platform side a series of 5 pipe supports were constructed to allow the pipe spools to be run directly to the Cassia 'B' riser. The same 11-foot elevation off seabed is maintained throughout. These supports can be seen on Figure 2.

The 26-inch and 48-inch riser locations are reversed with regards to their respective pipeline approaches. This was necessitated by the loads on the 48-inch riser, which caused it to be installed on the jacket leg. Rather than install crossed tie-in spools, the crossing point was placed on the manifold. This arrangement has several advantages:

- Fabrication takes place onshore;
- Crossing of the 26-inch and 48-inch spools is performed during manifold fabrication;
- The 26-inch and 48-inch pipeline separation is by provided by mechanical support on the manifold skid, and not subject to erosion or settling;
- It allows the 20-inch tie-in piping to be installed at the 26-inch/48-inch crossing location, minimizing the pipe runs between the two systems.

System Flexibility and Expansion Potential

The manifold design allows for both isolation of the 40-inch from the 48-inch pipeline system and for future expansion of the system of the 48-inch system.

Once Cassia 'B' is operational flow between the 40-inch and 48-inch pipelines can be stopped by use of the isolation valve on Skid 13. In the event of damage to either system this same valve will allow one at least one line to remain operating.

Should the need arise for maintenance or repair of actuated valves or the check valve (the 20 isolation valve, 26-inch ESD and the 48-inch check valve) they can be isolated from the rest of the system via DBB valves.

The manifold is design to allow for several system expansion scenarios. Any future fields developed to the south of Cassia 'B' can easily be tied-in to the 36-inch hot-tap in Skid 12, providing they are exporting gas. Multi-phase or condensate pipelines from southern fields could be tie-in through the 20-inch hot-tap located on the 26-inch tie-in (Spool 7). In the event that BP wishes to extend the 48-inch system beyond Cassia 'B', the Cassia 'B' 48-inch export riser can be tied-in to the 36-inch dead-leg with no reduction in capacity. This new line would have to be tied-in to a facility that would allow operational and intelligent pigging of the 48-inch system.

Location of Safety Systems

Cassia 'B" is designed to both receive and export gas and condensate. One of the HSE requirements is that the platform has a fail-safe system for isolating it from the pipelines in the event of an accident. Both a 48-inch check valve on the export pipeline and a fail-closed ball valve on the Kapok import pipeline are required. These were incorporated into the manifold to provide easy access to the valves and to protect them from third party damage. These systems were flange installed on the outboard side of the manifold to allow removal and maintenance or replacement if required. The check valve is a passive system once activated. The 26-inch ESD ball valve will be connected via umbilical to Cassia 'B'. In the event of either a "close" signal or a loss of signal the 26-inch spring return will close the valve. The umbilical connection is alongside the 26-inch tie-in flange and all control equipment and tubing is run inside the manifold frame for protection.

Procurement and Logistics Challenges

Procurement of equipment for the manifold was straightforward for all but some of the 48-inch items. While 48-inch pipelines have been installed before, very few manufacturers have any experience in this size subsea equipment. The 48-inch procurement and fabrication was not one of simply scaling up the previous 40 or 42-inch design.

The manifold contains the world's largest subsea gas pipeline check valve, which weighs over 30 tons. It took several attempts before a successful cast was made, largely due to its shear size.

Logistics of handling and shipping 48-inch valves and bends was challenging. All of the 48-inch size components required heavy equipment to move. As an example, the pup pieces for the 48-inch manifold bend had to be shortened to allow the bend to fit on a transport truck.

Design Basis

The significant design criteria for the manifold were as follows:

- Design life, 50 years
- Design pressure 1480-psig
- Hydrotest Pressure 1850-psig
- Seismic loading .22G

Current and wave loading are given in Table 3 and soil data is given in Table 4 below. . The waves and current data given in Table 4 is treated as omni directional.

Parameter	Return Period		
	100 Year	10 Year	1 Year
Wave Period (s)	11.5 s	10.7 s	9.9 s
Significant Wave Height (ft)	25	14	12.57
Steady Current Velocity (ft/s)	1.833	1.303	1.26

Table 2
Wave and Current Data

Depth (ft)		Soil Type	Shear Strength - Su (lbf/ft^2)
To	From		
0	0.5	Elastic Silt with few sand pockets	50
0.5	1.5	Elastic Silt with few shell fragments	140
1.5	8.5	Sandy	130
8.5	10	Silt	230

Table 3
Seabed Soil Data

Piping Design

Piping Layout

Prior to designing the structure the piping layout is required. To do this the following information is considered:

- Tie-in locations and orientations;
- Bend sizing, valve and tee spacing to allow intelligent pigging.
- Piping cross connections
- Number, size, locations, and basic types of valves (ball, check etc.);
- Flange locations and types;
- Control and actuation systems requirements.
- Lifting method and Center of Gravity (CoG) requirements.

Skid No.	Tie-In	Desired Orientation
17	26-inch to Kapok	Facing east
16	26-inch to Cassia B	Not facing south, and must be west of the 48-inch tie-in to Cassia 'B'
12	48-inch to Beachfield	Facing west
11	48-inch to Cassia B	Facing North
13	20-inch to 40-inch pipeline	Facing north or east
18	36-inch dead-leg	Facing north
12	36-inch gas line hot-tap	Facing south
7	26-inch multi-phase line hot-tap	Facing south or east

Table 4
Required Tie-In Orientations

Based on the above criteria the tie-ins were placed as shown schematically in Figure 4.

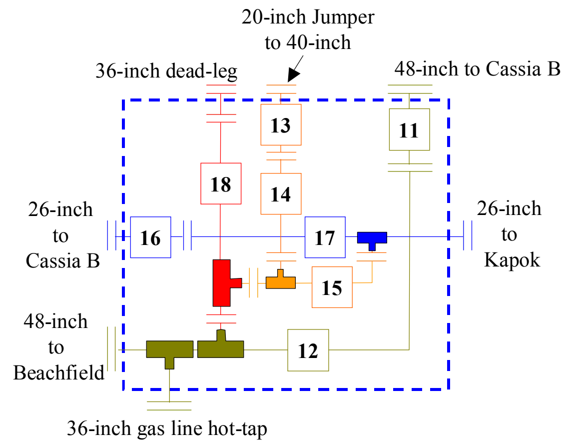

Figure 4
Manifold Layout

The next step was to place the 48-inch bend and determine the valve and tie-in tee locations. The location criteria used are given in Table 6 below:

Description	Number of Valves	Requirement
48-inch Check Valve	1	Active device; must be located on an outer edge of the manifold for easy access.
48-inch Ball Valves.	2	Must be downstream (towards Beachfield) of the check valve, and upstream of the 20-inch jumper.
26-inch ESD Ball Valve	1	Active device; must be located on an outer edge of the manifold for easy access.
26-inch Ball Valves	2	Must be upstream (towards Kapok) of the ESD valve, and downstream form the 20-inch jumper.
20-inch Actuated Ball Valve	1	Active device, must be located on an outer edge of the manifold for easy access.
20-inch Ball Valves	4	2 valves must isolate the actuated ball valve from the rest of the manifold piping. 2 additional valves must isolate the 26-inch from the 20-inch jumper piping.
36-inch Ball Valves	2	Must isolate the 36-inch tie-in flange from all manifold piping, and tie-ins.

Table 5
Valve and Tie-In Tee Location Criteria

The resulting piping configuration is shown in Figure 5.

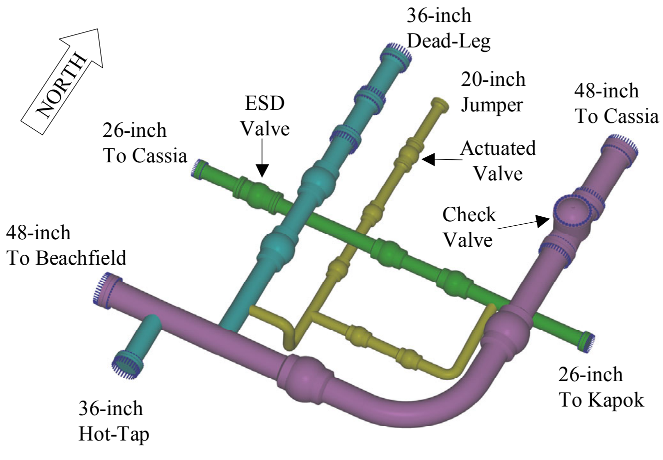

Figure 5
Final Piping Configuration

Flanged Connections

While the manifold reduce the number of subsea flange make-ups by 6 (from 21 to 15), the number of flanged connections in the system was only reduced by 3. This is due to the philosophy of making any active device flange connected. These connections were made-up and hydrotested prior to deploying the manifold.

Several factors including weight, long term reliability, positive sealing, the ability to test the connection through a port, and tolerance for small misalignments led to the use of Taperlok flanges for the manifold on all but the future 36-inch connections. The decision was made to use standard ANSI flanges for the future 36-inch tie-ins as these future lines, if they are ever used, will have a shorter design life and flanges of an unknown type. ANSI flanges are also far more common and easier to procure than Taperlok flanges.

Piping Design

The manifold piping was analyzed using AutoPipe. The piping was modeled as an integrated system and checked for installation, testing, and operational loads. The integrated system included the last 1000 meters of 26-inch and 48-inch pipelines; all pipeline tie-in spools; the base of both risers; and all manifold piping. By modeling the entire system a more accurate assessment of the pipe loading could be determined. The output loads from the AutoPipe were fed in to the SACS model created to analyze the manifold structure.

Center of the Gravity Force

Keep the center of gravity centered on the structure was a primary design consideration. The center of the gravity force (CoG) was calculated for the combined piping and structure using the load summation facility of SACS. The results are given in Table 4 below and show that the resultant CoG is very near to the geometric center.

Center of Gravity		
X (ft)	Y (ft)	Z (ft)
0.55	-0.09	7.88

Table 6
Structural Center of Gravity

The X and Y measurements are taken from the geometric center of the manifold and the Z is measured from the bottom of the structure.

Structural Design

Design Goals

Once the piping layout was determined, design of the supporting structure was carried out to:

- Meet all functional, operational, installation and maintenance requirements.
- Minimize cost and meet project schedules
- Comply with specified codes and regulations with due consideration to fabrication, installation and operation.
- Ensure the manifold can safely be lifted and deployed to the seabed.
- Ensure the manifold is able to safely withstand normal operational loads and extreme environmental loads including seismic loading.

Allowable Stress Design Criteria

The structural members of the manifold are in accordance with the ASIC code for structural steelwork and API RP 2A. The allowable stress design criteria for the structural members are:

- Bending Stress = 0.66Fy
- Shear = 0.4Fy
- Tensile = 0.6Fy

Fy is Yield Stress. A 1/3 allowable stress increase is allowed for extreme environmental loading. A 70% allowable stress increase is allowed for seismic loading. The joint punching shear check is in accordance with API RP2A.

Structural Model and Layout

The structure and piping were modeled using SACS software. The structural model is shown in Figure 4. The base deck consists of W27x84 rolled I beams. The framing consists of varied diameter pipe. SACS was used to model the dynamic and static loads in the structural members and to calculate the resultant loads at the piping connections for input into the piping model. The process was iterative, with the calculated pipe support stresses due to piping weight and hydrodynamic drag and expansion and pressure loads were input into the SACS structural model.

As part of the structural design diver platforms were installed at the tie-in locations. These platforms functioned to both help guide the spools into alignment and as work platforms that allowed the diver to work standing up.

During the structural design process care was taken to ensure that there is easy access to all piping and equipment. This facilitated the onshore fabrication and enhanced the divers efficiency and safety. The resulting structure has a foot print of 58-ft by 60-ft (not including the diver platforms) and is 20-high.

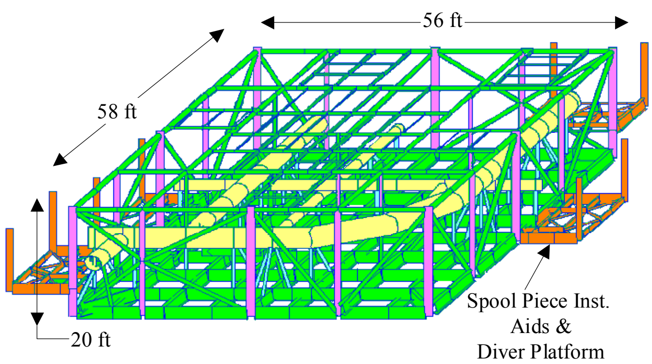

Figure 6
SACS Model

Fabrication Analysis

The structure was examined for stresses during fabrication. The governing case is the loads caused by the hydrotest of the manifold piping. The highest stress in the structure occurs in the pipe supports, which reach 70% of the allowable.

Installation and Lift Analysis

Typical in air lifting analyses were carried out to check all the structural members and padeyes. In accordance with API RP 2A, safety factor 1.35 was used to check the structural members, and safety factor 2.0 used to check the padeye and adjacent members. The load combination coefficients include the 2% contingency and other weights from supports and welding.

The stresses in structural members never exceeded 70% of the allowable for those not adjacent to padeyes, and 90% of the allowable for those that were.

As the manifold was deployed with the piping sealed and empty, the installation and lifting stresses were much lower when the manifold was submerged than for the lift in air.

Operational Analysis

For the operational conditions the following cases were examined:

- Standard operating conditions, 100-year storm loads;
- Subsea hydrotesting;
- Standard operating conditions 1-year storm conditions with seismic loading.

The structural stresses in both the 100-year storm and subsea hydrotesting cases never exceeded 50% of the allowable.

The manifold will be located in the seismic zone and a dynamic spectral seismic analysis was performed to verify the strength and ductility of the manifold. The highest stresses occur in the pipe supports, which go as high as 92% of the allowable. The seismic loading analysis was performed using SACS with input data from a seismic spectral data study performed for the Cassia 'B' platform.

Foundation Design

A mud mat under the manifold is required for permanent stability on the seabed. It has been designed with a safety factor of 2.0 in bearing and with a safety factor of 1.5 against sliding under installation and operational conditions following the API RP 2A shallow foundation design guide.

The maximum theoretical pipeline loads plus structural submerged weights are input to act on the mud mat. This value is considered appropriate for a sand-to-sand interface. It should be noted that the stability in the longitudinal direction is assisted via the pipeline. The distribution of the applied loading to the foundation is modeled (SACS analysis) using spring supports below the main deck of the manifold.

Conclusions

The manifold installed near the Cassia 'B' platform as part of the BP Bombax project achieved the Primary and Secondary goals of the design. The manifold provides BP with flexibility with regards to future developments as well as allowing for augmented production prior to Cassia 'B' platform being completed, while at the same time minimizing the seabed congestion South of Cassia 'B' platform.

The manifold performed as designed during installation and pre-commissioning of the 48-inch and 26-inch pipeline systems.

Acknowledgments

J P Kenny Inc. would like to thank BP for the opportunity to work on the Bombax Pipeline Project and publish this article.

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