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DEVELOPMENT OF HIGH-PERFORMANCE PREMIUM THREAD CONNECTION DEDICATED TO PRE-SALT CHALLENGES

Martins V.[1], Luongo M.[2], Delbosco T.[3], Martinez J.[4]
Co-Authors: Durivault J.[5], Penven F.[6]

Abstract

This paper brings, through actual examples focusing on Pre-Salt Premium connections, the design process and the key elements that need to be considered in the design of a high performance premium connection, from the sketch to the manufacturing process, including the ways to optimize the design features and performance as long as the different methods and tools required to validate the connection designs. It will be also presented the methodology followed by the manufacturer to design and validate a proprietary connection, starting from design features selection, firstly evaluating and optimizing by FEM (Finite Elements Method) and then tested in full scale conditions in make-and-break and pressure sealability under combined loads in static frames. Then iterative design loop steps was needed to reach the targeted performance and design extrapolation of the same design rules together with FEM comparative validation allowed us to extend the tested design to more sizes ,weights and grades combinations. Considering the number of well phases to be installed, the clearance between casing strings was a major driver for the well design. The OCTG pipe supplier work based on industry and operator inputs, to design, test and qualify optimized T&C (Thread and Coupled) casing connections fitted on odd pipes diameters (non API 5CT sizes). The connection was designed to achieve the required tensile, compression, internal and external pressure performance and to ensure a suitable clearance with the upper casing string. Achieving similar performances with Special Clearance (SC) Designs on T&C connection it was a great achievement with also no precedent in the Industry. The operator has benefited from this tailored connection designs by being able to both drill the challenging Pre Salt wells and optimize the production flow as the casing sizes and designs have been specifically selected to be able to fit the exact required tubing size.

Keywords: Pre-Salt, Challenges, Premium Connection.

1. Introduction

The Brazilian Pre-Salt has an area of approximately 149,000 square kilometers, extending from the coast of State Santa Catarina to the State of Espírito Santo coast, located in depths ranging from 5.000 to 7.000 meters. To reach the reservoir, there is a value greater than 1.500 meters of water depth and a layer of salt that can reach 2.000 meters, mainly

[1] S. America M&D – Vallourec
[2] R&D group Manager – Vallourec
[3] R&D Engineer – Vallourec
[4] R&D/Tech support manager - Vallourec
[5] Global Connection M&D manager - Vallourec
[6] M&D Manager - Vallourec

consisting of halite (sodium chloride) and anhydrite (calcium sulfate). In front of this scenario it was required effective solutions to meet the new challenges placed on casing string. Therefore, OCTG thread connections must withstand extremely high levels of combined loadings while maintaining structural and sealing integrity. This paper brings, through actual examples focusing on Pre-Salt Premium connections, the design process and the key elements that need to be considered in the design of a high performance premium connection, from the sketch to the manufacturing process, including the ways to optimize the design features and performance as long as the different methods and tools required to validate the connection designs.

One of the most critical challenges faced by casing string on Pre-Salt is the Collapse load, the salt rock behaves as a thermo-viscoelastic material which has the tendency to creep when subjected to stress. The viscosity of the salt rock is responsible for wellbore closure as a function of time, creating difficulties for well construction especially for casing that can fail in front of the salt during the well life, that for Pre-Salt was calculated as 25 years. In order to attend this technical particularity it was necessary to develop Premium connections with heavy walls pipes to withstand the collapse loads exerted by the thick salt layer. As a consequence of the quantity of heavy pipes along the casing string another mechanical load becomes critical, since the casing string can reach up to 5.000 meters of depth, thus the Premium connections must support all this weight, which means high Tension resistance. The other particularity of Pre-Salt is the High Pressure found at the reservoirs, with values approximately of 15kpsi, demanding again high performance of connections, in this case the Internal Pressure resistance. Last but not least, in some fields the high Temperature also contribute for the action of compressive loads along the casing string, beyond that, based on operator's well designs a strong exigency was put in place by the end-users to have connections with smaller Outside Diameter than standard connections (that is also a big challenge as long as smaller wall thickness represents less resistance). All those specific technical requirements demanded the development of dedicated Premium connections for Pre-Salt Operators, never needed by the industry before, which will be detailed in this Paper.

2. Connection validation

2.1. Connection design analytical and FEM evaluation

In order to answer the needs for Brazilian Pre-salt requiring high performances as well as clearance constraints, tailor-made approach was used for designing the corresponding connection.

Thanks to understanding many of the challenges possibly faced by Operators while drilling Pre-Salt reservoirs, VLR focused its work manly in two types of connections, were then designed, Threaded and Coupled (T&C) with special clearance option (SC) and flush integral connection (maximum outer diameter of the connection being the same as the pipe).

Design being tailor-made, several options were evaluated, especially extrapolation from existing product line and/ or newly designed connection. Both options were done done using VALLOUREC analytical design criteria permitting to evaluate the ability to reach the performance (as an example, critical cross section of the connection is used to check that the required tension can be reached) while respecting the clearance constraints (internal for the drift and external for the clearance with the previous casing).

Following design evaluation using analytical criteria, FEM was used in order to optimize and validate the design done or give a level of confidence, especially for their ability to withstand the loads and alternative sequences of internal pressure or external pressure combined with tension or compression as required by the API RP 5C5/ ISO 13679: 2002 CAL III and CAL IV.

2.2.Connection physical qualification

Last step of connection validation was done according to the API RP 5C5/ ISO 13679: 2002. Indeed, since 2002, ISO13679 1st edition/ API RP 5C5 3rd edition has been the industry standard for premium connection testing in OCTG. ISO 13679/ API RP 5C5 was built to provide a standard to the industry for the evaluation of premium connection performance detailing especially samples geometry, testing procedures for M&B, seal ability and failure tests, loading points definitions and calculations methodology. ISO 13679/ API RP 5C5:2002 define a methodology to evaluate a connection performance (called CAL level) but does not define the connection envelope stating that “the connection manufacturer should provide a complete test load envelope and limits loads for the connection” (ISO 13679 / API RP 5C5:2002, B.4.2, pg71). A connection qualification being defined by the envelope and the CAL level reached meaning both are required to define a performance.

Three different types of combined load cycles are defined in ISO 13679 / API RP 5C5:2002 (Series A, Series B and Series C). These combined loads cycles are based on a combination of the type of loads a pipe can be subjected to and may be performed at different temperatures (Ambient for series A and B/ Elevated for series C) and with different media (liquid or gas) depending on the CAL targeted. They are intended to cover the connection Von Mises Envelope in the maximum capacity expected by such connection when considering a determined CAL level and their sequence may not be typical of any application:

- Series A: Tension/Compression alternating Internal/External Pressure (IP/EP)
- Series B: Tension/Compression with Internal Pressure (IP) with/without Bending.
- Series C: Thermal cycling

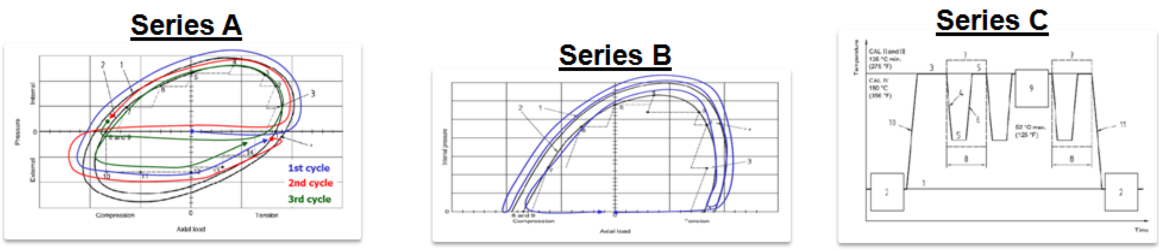

Figure 1. ISO 13679 /API RP 5C5:2002 Series A, B and C main characteristics

Targeted ISO 13679 / API RP 5C5:2002 level for Brazilian Pre-salt depends on the application and can required CAL II to CAL IV. This required M&B tests, seal ability tests (series A, B and C) and failure tests on various geometrical combinations (see figure 2. Presenting ISO 13679 / API RP 5C5: 2002 CAL IV protocol).

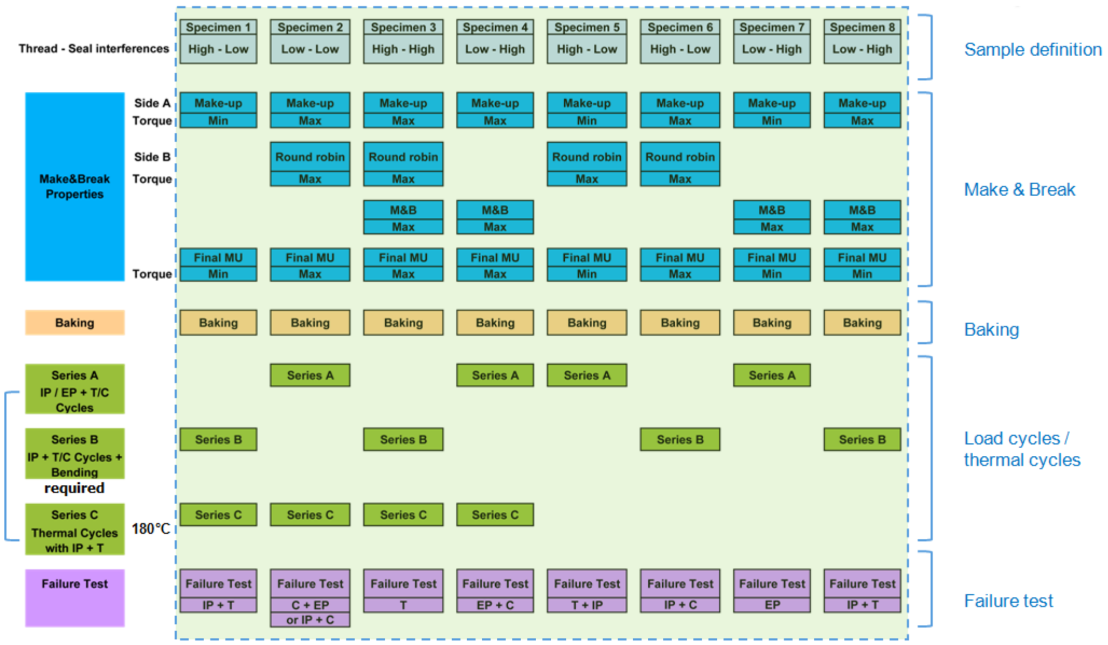

Figure 2. ISO13679/ API RP 5C5:2002 standard: CAL IV

As described in ISO 13679 / API RP 5C5:2002, abbreviated test can be done especially to take into account existing data (see ISO 13679 / API RP 5C5:2002, "5.1.3 Abbreviated tests and deviations" pg.10 and ANNEX G pg.122), type of connection (T&C or integral) and the targeted CAL level. As a minimum requirement, for a M&B and seal ability with worst case geometries have to be done.

2.3.ISO 13679 / API RP 5C5 evolution

Over the last years, ISO and API committees issued revised version of this standard to better fit with downhole conditions. Main drivers were:

- To have combined loads at elevated temperature, whereas ISO13679/ API RP5C5:2002 was not requesting any test at elevated temperature (except thermal cycles in Q1 quadrant of VME (Series C)).
- To have internal pressure and external pressure tests at elevated temperature tests,
- To add Q1 (ambient) - Q3 (elevated temperature) cycles reflecting worst case discharge condition.
- To test connections considering a more accurate material characterization and in the very extreme tolerance range in term of samples geometry

A first draft standard was issued in 2009, ISO 13679:DIS2009, but not adopted, that especially introduced Series B at elevated temperature and extreme tolerances.

Following version in 2011 became a FDIS (final draft) but was rejected during ISO country vote. This ISO 13679:FDIS2011 kept elevated Series B, adding Series A at elevated temperature (IP & EP at elevated temperature) as well as modified load calculation formulae that made the testing more severe.

Although rejected, this ISO 13679:FDIS2011 set the basis for API to build the upcoming standard, main focus was to avoid near-yield cycling of material, caused by the high number of cycles at the very limit of the yield limit (especially combined with elevated temperature).

End of 2015, API issued a ballot draft for final review and comments. This draft has been officially approved in January 2017 to become the new standard for OCTG premium connection testing (API RP 5C5 4th version).

3. T&C connections with isolated design development

Customer required T&C connections on 10 3/4” and 13 5/8” pipes. Developed connections have been considered as isolated products to maximize the design options at hand to meet both clearance and performance requirements. Specific designs for all these sizes use current VAM® 21 product line design elements that can be summarized by the listed features below:

- Internal metal to metal seal combined with extended lip, double taper guide & multi-grooving in order to ensure both pressure resistance and gas tightness. Seal is also protected from rough handling thanks to its position on the connection.
- Internal shoulder combined with lip stiffness effect for torque, compression and external pressure capability.
- An optimized Thread profile to guarantee no cross-threading, self-alignment stabbing and improved galling resistance.
- Multi-grooving system to avoid any dope pressure build-up and then be sure to have clean make-up charts.

For connections related to 10 ¾ pipes, the main challenge was to ensure compression ratings higher than tension limited by SC options chosen due to clearance constraints despite the restricted coupling OD constraint (Special Clearance of 70% and 82%).

Each requested diameter has been developed separately but using the same methodology presented in the paragraphs below.

3.1. Listing of all potential concepts

Regarding all best in class design features known within the product line, a list of potential concepts is raised to meet customer requirements. Each concept has some advantages and drawbacks and that’s why several designs with different design features are considered.

3.2. Design concepts evaluation

All above concepts have been evaluated. Being based on product line features, most items to evaluate the concepts are already well-known and references exist. However, main driver for selection are the best compromise between the performance, the cost and schedule item. The following performance items, customary for VAM® 21, have to be checked for each concept:

- Behavior of the connection under high tension through design criteria,
- Make-up kinematics and anti-galling performance through design criteria and finite element analysis (FEA).
- Seal-ability performance through finite element analysis (FEA).

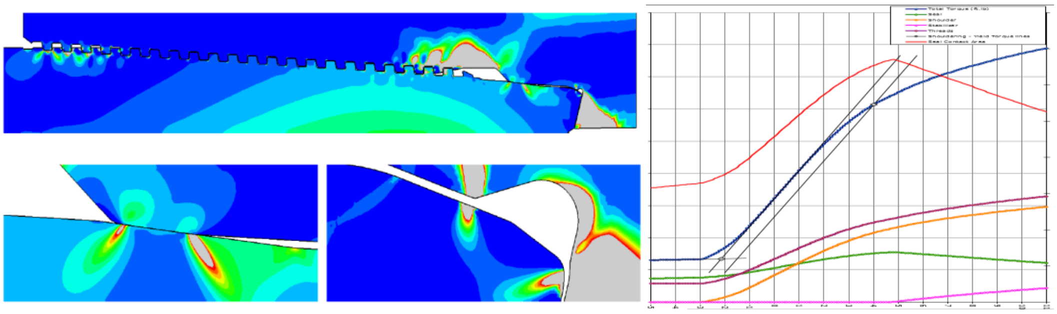

Figure 3. Connection behaviour analysis using FEA for the 10 3/4" 85.3# HW-NA

These parameters are compared to the critical sizes of their base design to stay as close as possible to the product line scope of validity. After several design adjustments conducted using a first loop analysis and once several potential candidates have been identified, a second loop has been performed until the final selection of the best concept.

3.3. Connection validation

Thanks to product risk analysis, a validation plan is defined according to information from design concept evaluation. The purpose of this validation plan is then to assess all risks coming from design modification needed to fulfill all customer requirements.

For the 13 5/8" 88.2# NB version, the following testing program has then been conducted:

- Physically perform Make & Break tests in the most critical connection configuration ("LH" and "HH" interferences respectively meaning lower range of interference on the thread and upper range of interference on the seals. Upper range of interference on the thread and upper range of interference on seals according to product drawing and tolerances of manufacturing).
- Physically perform sealability tests following abbreviated ISO13679:2002-CAL IV in the most critical connection configuration. Our confidence to product line reliability has allowed us to target greater CAL assessment (CAL IV instead of CAL II) than the customer request.

For the 10 3/4" 85.3# HW-NA and the 10 3/4" 73.2# HW-NA, the following testing program has then been conducted:

- Physically perform Make & Break tests on the most critical connection configuration ("LH" and "HH" interferences respectively meaning lower range of interference on thread and upper range of interference on seals and upper range of interference on thread and upper range of interference on seals according to product drawing and tolerances of manufacturing). Extrapolation of the anti-galling performance was possible using physical Make and Break tests performed on the 10 3/4" 85.3# HW-NA for the 10 3/4" 73.2# HW-NA (highest criticality in terms of thickness and grade.)
- Physically perform sealability tests following abbreviated ISO13679:2002-CAL IV in the most critical connection configuration ("HL" and "LL" interferences respectively meaning upper range of interference on thread and lower range of interference on seals and lower range of interference on thread and lower range of interference on seals according to product drawing and tolerances of manufacturing). Our confidence in the product line reliability has allowed us to target a greater CAL assessment (CAL-IV instead of CAL-II) than the customer request.

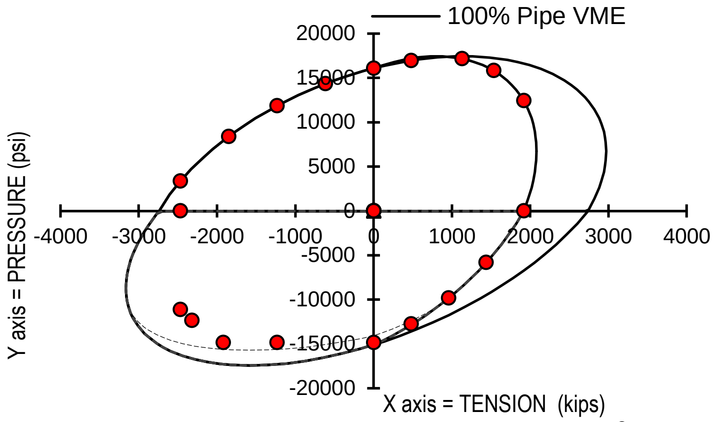

Figure 5. Performance envelope of 10 3/4" 85.3# VM110 HCSS VAM® 21 HW-NA SC70

4. Flush integral connections development

Customer required flush connections on 5”, 7 5/8”, 9 7/8”, 10 ¾”, 11 7/8”, 13 5/8”, and 14” pipes. It was designed specific designs for all these sizes, keeping a same basis for all designs, which present on the following common features:

- Internal and External metal to metal seals, insuring pressure resistance and gas tightness.
- External Shoulder, providing torque and compression capability, in addition to accurate seal positioning.
- Double-Start Variable width thread (Dovetail thread profile with axial gap), for fast make-up and easy running. It locks radially pin and box and prevents from jump-out. It is important to mention that since the threads are not self-locking, there is no risk of dope pressure issue that is commonly known for self-locking threads.

Due to the very large range of diameter requested, from 5 inch to 14 inch, the design file was split in two, one for smaller diameters (from 5” to 10 ¾”, called VAM® FPO) and one for larger diameters (11 7/8” to 14”, called VAM® BOLT-II),

For both connections, two main behaviors must be validated. The first one is the anti-galling performance and the second one the sealability performance.

Since loads and functions of all OCTG are not the same (for instance between a surface liner and a completion tubing string that is the first barrier to reservoir fluids), these ISO/API standards different levels of performance, called Connection Application Level (CAL), ranging from I (for the least severe) to IV (most critical).

For the end-user need of flush connection, the main challenge was to get high performance products that could withstand external pressure loads (pre-salt conditions often ask for high collapse ratings) and internal gas pressure, all this combined with axial tension and compression loads, depending on well load cases during the lifetime of the well.

This is translated into the customer requirement of qualifying all the designs as per a minimum testing protocol corresponding to CAL III of ISO13679:2002 standard. This is the minimum CAL for which the loads applied during the testing sequence have external pressure combined loads. CAL I and CAL II of ISO13679:2002 do not have such external pressure envelope testing. CAL III also tests at 135°C elevated temperature.

4.1. Anti-galling resistance

Anti-galling resistance is the connection capacity to support high level of contact pressure during the connection make-up without damaging the threads, even in the case of multiple make-up and break-out.

The first development stage was to optimize the seals designs, by considering the most critical configuration during the make-up, in order to cover a wide range of operations scenarios. In order to validate the anti-galling performance, the procedure is as follow:

- Determine the most critical size in terms of anti-galling resistance (OD/wall thickness/grade comparison – Galling criteria and or FEM analysis by simulating the seals engagement using specific software.
- Physically perform Make & Break tests on the most critical size in the most critical connection configuration (“LH” interferences preferred meaning lower range of interference on thread and upper range of interference on seals according to product drawing and tolerances of manufacturing).
- One specific challenge for these pre-salt operations is the specific grades used, such as Super13% chromium material, and the relatively heavy wall sizes, that are 2 factors known to be critical for galling resistance.

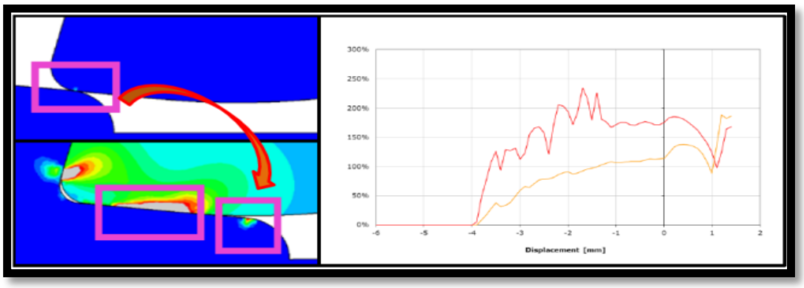

Figure 6. Galling risk evaluation_Comparison through FEA

The flush designs developed met the make & break requirements required by ISO 13679 / API RP 5C5 standard for casing applications, for all material and weights considered.

4.2. Sealability performance validation

2 different approaches were made depending on the range of OD: for the upper range (VAM® BOLT-II) a product line validation approach was done, while the smaller range of flush product (VAM® FPO) was optimized with focusing on the very specific products requested by customer, testing of some size (extrapolation of the other ones), grade and weight requested by customer directly.

For product line validation, in order to determine the sizes to be tested, the polygon approach was used, in compliance with API Standards. The goal of this approach is to plot each design using the D/t (Outside Diameter divided by the wall thickness) ratio. For each outside diameter, associated D/t ratio is calculated. “D” means outside diameter and “t” denotes wall thickness.

This method is presented in a document named “Procedures for testing Casing and Tubing connections / API Recommended practice 5C5 Fourth Edition, January 2017 (ANNEX F – Product Line Validation – Figure F.1).

The API RP 5C5: 2017 requests to test the corners of the polygon through a full-scale physical testing (CAL II in these cases, which is equivalent in criticity to CAL III on the standard ISO 13679:2002). These tests should be performed in a high strength (API 5CT Q-125) in order to ensure that a high internal pressure rating can be accomplished. Concerning the low grades (API 5CT L-80), only the corners with a low D/t ratio should be tested with a reduced specimen test.

Then, sizes placed at the corner are selected to be physically tested according to API RP 5C5: 2017 - CAL II (based on this method, sizes inside the polygon are considered validated).

First designs were generated and validated using FEM analysis by studying common outputs from simulations. The best ones were selected as the official designs. Furthermore, to strengthen the design selection, a multi-criteria approach was set up based on R&D expertise. Physically tested designs were simulated with actual dimensions, grades and envelopes (as per real testing) in order to create new criteria based on numerical simulations.

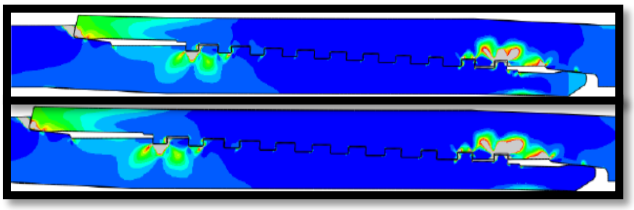

Figure 7. ISOCOLOR representation of one flush connection design – 80ksi (up picture above) & 125 ksi (down picture above).

After an investigation, reliable criteria were selected and “mixed” by applying weighting coefficient and normalize them. Each new design (in 80 ksi HC and 125 ksi HC) is then compared with the references, indicating whether the design is good or not.

Since the performance level required by end-user is a high technical challenge especially for flush connections, it was discussed how to answer customer need without over-specifying the product specification. Indeed when looking at well loads for such application, it is seen that some areas of the Von Mises Ellipse of the string do not see much loads. It is particularly true for “Q4” quadrant, the one combining tension with external pressure. It is very rare that well load simulations show any load having high tensile value with external pressure.

However thanks to our experience in designing and testing premium connections, and especially integral ones, we could anticipate that having to go to the limit in Q4 would raise the risks for the product. Since this would bring no value to customer, and truncating this quadrant Q4 would still bring all integrity and performance needed for the pre-salt application, it was agreed to apply this truncation to the VME for the ISO 13679 / API RP 5C5 protocols.

For isolated designs approach (smaller diameter) on purpose testing protocol was performed on the specific combinations, again testing on high collapse loads in external pressure, making it challenging for the product.Following the analysis of well loads, some VME truncations were accepted as they were not part of the well loads for the application, and it was a good way to reduce project risks and development timeline.

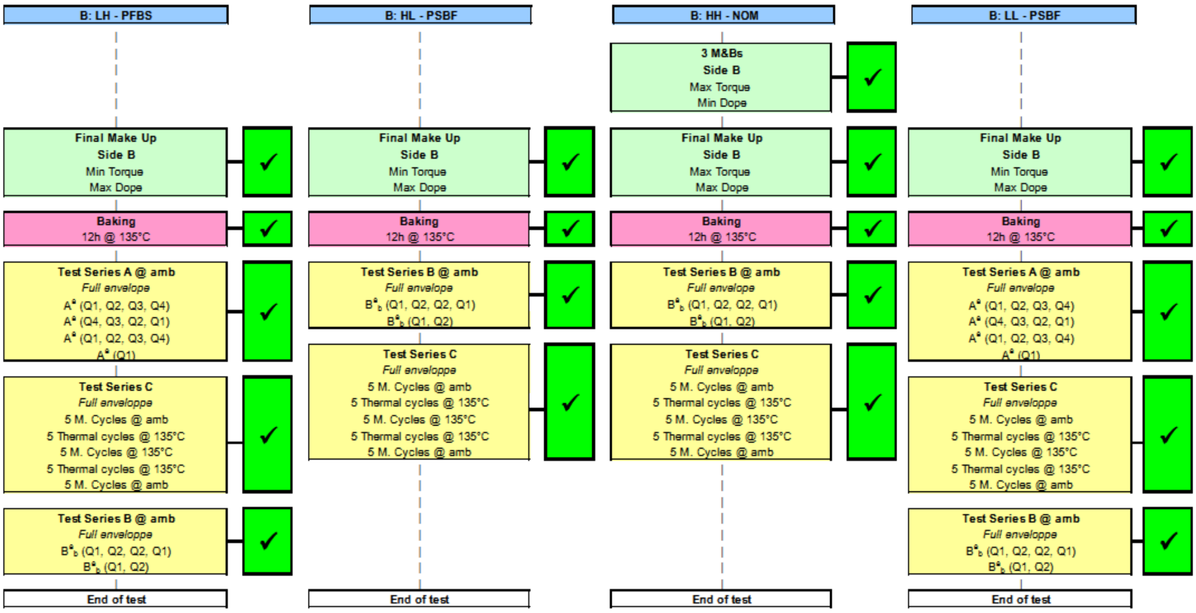

Figure 9. Validated testing protocol according to ISO13679:2002 – CAL III (including customer requirements).

As a last step of connection design validation both for T&C and Flush designs, trials of run-in-hole in real rig conditions were performed. Performances in rig running conditions were validated, testing in all different conditions of make-up speed, misalignment, stabbing, equipment used, torque level, and make up compound used.

This enabled to provide a full recommendation for running the product, with focusing on the customer running conditions and equipment for their offshore application.

5. Conclusion

This paper described in details the efforts made by the OCTG supplier to develop, test and validate Premium connections able to withstand and fulfill to all Pre-Salt challenges, ensuring the well integrity, which is one of the most important features to be considered in a well construction. Furthermore, the connections developed have been widely used in Pre-Salt wells confirming the reliability of the development and demonstrating also the importance to work in collaboration with the end-user using the correct effort to match needed performance with technical and economic resources pretend by the Operator.

6. Acknowledgements

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7. References

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