High Grade Steel Pipeline for Long Distance Projects at Intermediate Pressure

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Abstract

Natural gas could become one of the most important and strategic energy source in the years to come, even if the renewable sources growth will play a fundamental role in the "next green power energy"; however natural gas has the chance to assure a continuous and reliable energy supply on a economically viable, long term base span. Potential routes for gas export from giant mid-continental fields to end users market areas have been analyzed by the industry. These analyses included also optimisation on routing, material selection, definition of operating flow parameters, selection of optimum hydraulic diameter and wall thickness, sizing of intermediate gas compression stations, constructability and environmental impact analyses.
Several and independent technical-economical evaluations have been proven that natural gas pipeline transportation systems based on:
- semi-traditional construction techniques,
- high strength steel,
- high operative gas pressure (more than 10 MPa),
are the only options to for challenging projects aimed to exploit "stranded gas fields".
The improving know-how production routes of pipeline steels, made available on industrial market, since the 90', high strength steels such as L555MB (according to EN 10208-2 or ISO 3183) equivalent to API 5L X80 and grade 550 (according to CSA Z 245.1-07); while the interest on higher grade steels such as X100 L690MB (acc. to ISO 3183) or grade 690 (acc. to CSA) appears to be yet premature for a large scale industrial application being its evaluation still pending.
X80 steel pipes spread worldwide and the amount of laid lines continuously increased, thus demonstrating a consolidated trend in adopting X80 steel pipes as a standard solution for high pressure gas transportation. The largest development "in field" application" is in North America and in the United Kingdom where most of the operating X80 lines are located; even if the overall figure (in term of installed km is low compared to conventional steels as X65-X70). A rapid increase of long distance pipelines is expected in the next few years, as the rapid development of the Asiatic countries (especially China and India) is reflecting a higher energy demand and requires the construction of new pipelines for natural gas.
However the general lack of massive application of this technology pushed Majors to be engaged in filling the gaps to make available application over an industrial scale. Eni launched its first project on High Pressure High Grade Strength Steel in the 90', followed by a long series of others commitments (either proprietary and within cooperative projects). This paper describes specifically the project launched in 2008 and that it's expected to finish by the end of 2011, furthermore an analysis of the results got in previous experience is provided. The topic is the missing link between high pressure and conventional transportation pressure of onshore netgrid system, specifically the adoption of API 5L X80 pipeline steels (UOE & Spiral welded) to be used in pipeline (for intermediate pressure application, i.e.up to 12 MPa) even for harsh environments.

1) Introduction

The first “pipelines” were laid in China about 1000 B.C., while the first oil pipeline was built in Baku, 1878, it was above 10 km long and 2” in diameter and it was realized to decrease the cost of transportation by above 90%.

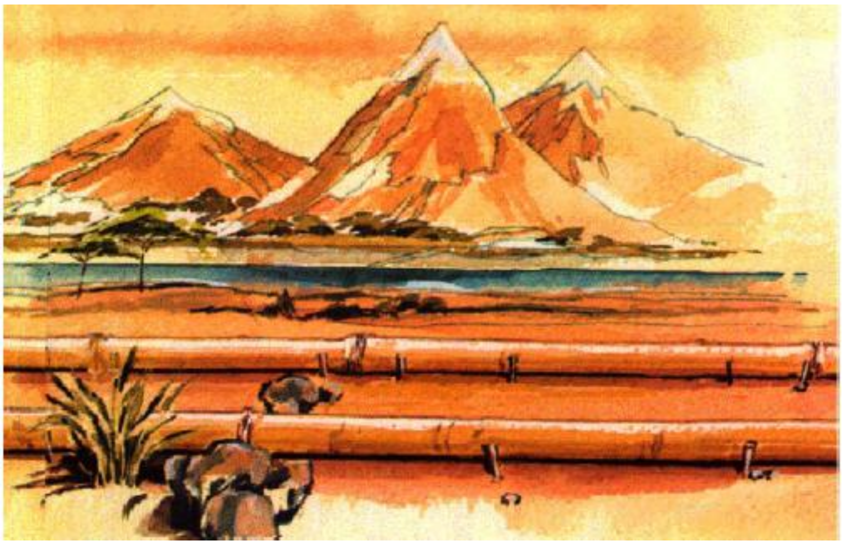

Fig 1. First pipeline made by bamboo in China about 1000 B.C. [1]

But looking at to the most recent development in pipeline industry, they were got as the steel manufacturing improved quality and productivity, basically we may divide the pipeline history in four main steps.
In the late ‘20s, when the manufacturers started to weld pipe with electric resistance-welded or flash-welded processes, that provided a relevant quality leap in the reliability of the longitudinal seam, at the same time the arc girth electrically welded were utilised; that brought a “tremendous upgrade” compared to acetylene weld. In that period, the steel producers began to develop material-quality standards for the safe design; the development of a national pressure piping code in USA started in 1915, while in March 1926, the American Standards Association initiated project B31. Later in 1935 the American Tentative Standard Code for pressure piping, B31, was issued. The control of the external corrosion had in the late ‘40s a real key stone as many pipeline operators introduced the cathodic protection for new pipelines. Later this concept was used to retrofit many old pipelines and in the ‘50s, even the older ones were upgraded with cathodic protection systems. In 1951, ANSI B31.4 & 8 were published. Some milestones in “in the trench” construction started in the same period with the large spread of radiography for girth welds at the installation phase; later the welder qualification and procedures qualification standards became common procedure to improve the girth welds reliability. However, the real big leap in pipeline steel quality started in the ‘60s, as the use of low carbon steels resulted in tougher grades. In that time other improvement in pipeline industry procedures, as testing all new pipeline construction by a hydrostatic pressure ”field” test, assured the proper serviceability of the pipe before its operational phase. The attention and safety for the existing pipelines was enhanced by the introduction of "in-line" tools; at that time they were able to inspect for corrosion defects on a “live”. Furthermore, the development of coatings gave another help for controlling the external corrosion. In the ‘70s the introduction of TMPC “Thermo Mechanical Process” was the latest breakthrough for increasing the pipeline steel strength, toughness without any detrimental effect on weldability, see Fig.2 and Fig.3a,b.

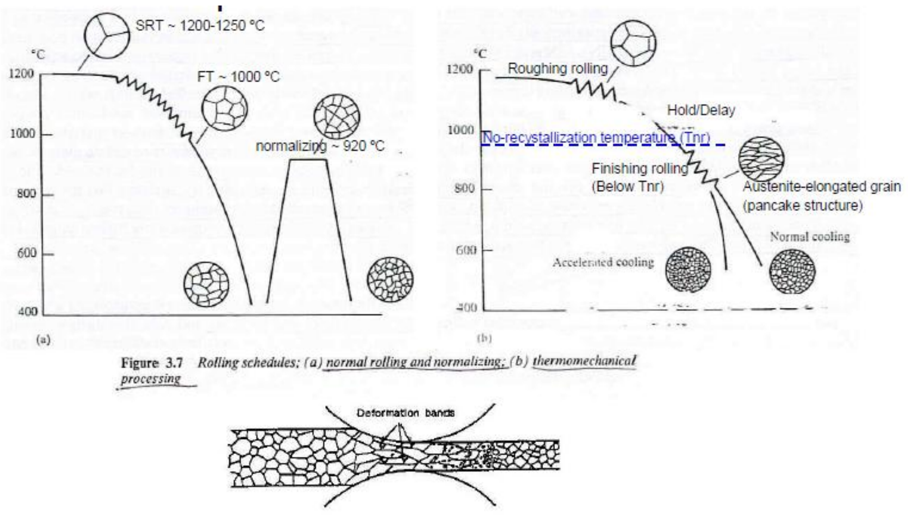

Fig 2. Rolling Schedules: on the left, normal rolling and normalising, on the right thermomecanical processing. [2]

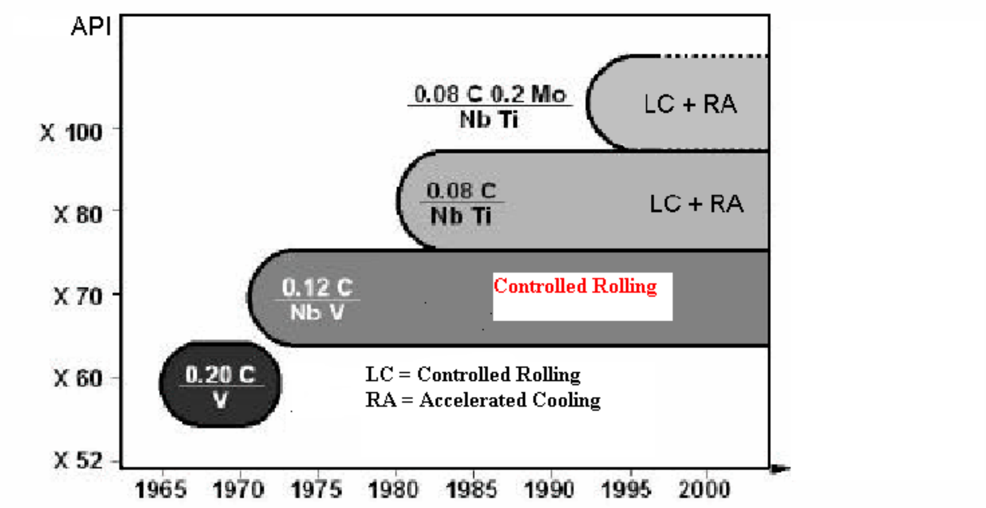

Fig.3a. Development of pipeline grade steels vs. time, and metallurgical "recipes"

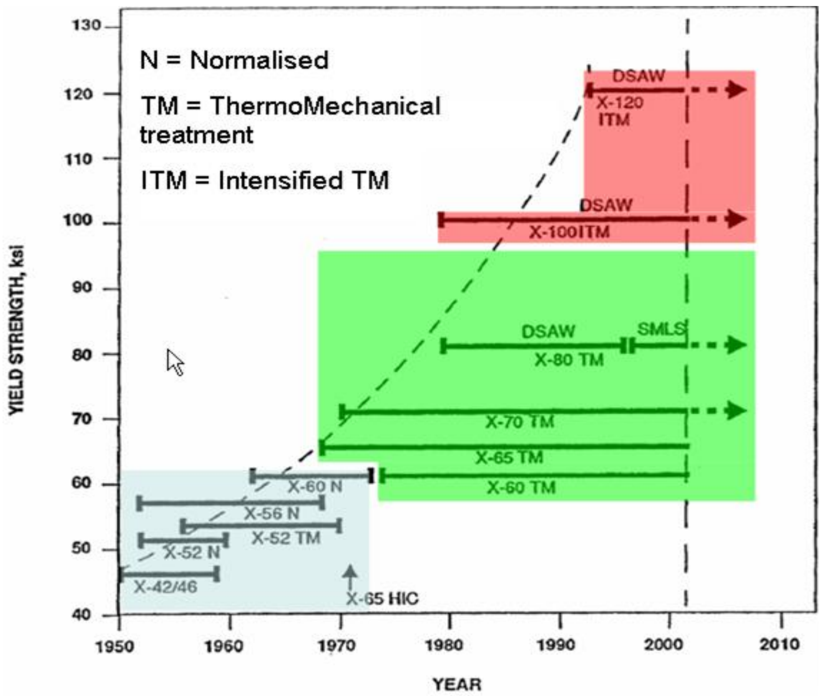

Fig.3b. Overall scheme on pipe steel and production technique evolution in the last 60 years

2) Evolution of Transportation Options

When selecting a transportation option for a pipeline project several key phases have to be passed through in the examination of the potential value, and associated risks, on the transportation overall cycle life; material selection and operational pressure are two of them.
The limit of 10 MPa for the onshore transport pressure, even if not specified within the international standards (and even by internal national regulation), is related to safety requirements; the main concern is the capacity that the steel used has to avoid the propagation of any failure due to an external interference and, therefore, limit the consequences of the massive gas emission on persons, property and environment. There are, anyway, sound technical reasons which lead to transport solutions at higher pressure:
- the transport pressure limit (in Europe the limit is often equal to 8 MPa), established during the Fifties, makes reference to the technology available at that time;
- the modern technology (it is convention considered after 1980) provides high quality solutions, both with reference to materials-construction and for the basic disciplines of engineering (flow dynamics, mechanics of fracture, new material production routes, soil-pipe interaction, engineering prediction tools, design criteria, etc.)
- high pressure and high transport capacity, therefore large diameters, mean high thickness that the operational experience of the networks – currently showed by a huge track record of above 10 million km of pipeline per operating years – indicates as the most effective measure against the damage due to external or mechanic interference, this damage being regarded as the most likely failure mechanism of a modern pipeline.
The role of availability of high strength steels in projects involving high pressure pipelines for shipping huge gas volumes over long distances is fundamental, even because in case of large diameters and high pressure there are some technological restrictions concerning the construction high wall thickness by considering that the minimum thickness required to the pressure containment is directly proportional to the steel characteristic strength.
Majors completed (and published the results) a Joint Industry Research Project in the late ‘90s (JIRP) finalised to indicate new line pipe fabrication specifications (see Fig.3b) for high grade pipelines (API 5L X100) and checking the pipe suitability to severe requirements in the installation and construction phase (welding) and for overall cycle life (structural integrity). Furthermore, further development was attempted to obtain steel with far higher grade (API 5L X120), for the gas transportation at a pressure much higher (25 MPa) than the one proposed in the latest studies.

4) Eni Projects on High Pressure

Eni started in the 1995 a cluster of projects on very high strength steel (involving X70, X80 and X100) combining experimental researches about the materials behaviour and theoretic studies about structural integrity and reliability by turning attention to the method for quantifying and qualifying the high grade steel characteristic strength, aimed to quantify reliability-based design criteria and reliable methods for selecting the design criteria; the final scope is to address the design phase towards quantitative safety targets for which the reliability level specified by designer and desired by operator is pursued. Now after the completion of this R&D stream, it is reached the conclusion that the use of X80 was a proven technology, even with all of the risks attributable to the use of the higher strength steel. However, the reason why X80 had so far not been employed worldwide for more pipelines was not due to any valid technical reasons, nor was it due to the absence of sufficient economic incentive. Rather, it was a general technical behaviour of “pipeliner” to be reluctant to be "first" in field application: that is always combined with short decision time in the project development phase driven almost entirely by commercial issues.

Only recently grade X80 steel pipes spread worldwide and the amount of laid lines continuously increased, thus demonstrating a consolidated trend in adopting X80 steel pipes as a standard solution for high pressure gas transportation. The largest development “in field application” is in

North America and in the United Kingdom where most of the operating X80 lines are located. Recently a rapid increase in grade X80 long distances pipelines is recorded also in Russian and Asiatic countries (especially China and India), reflecting a higher energy demand and requires the construction of new pipelines for natural gas.

Last two decades development in high performance pipeline steels for Oil&Gas industry and construction techniques have been the booster for allowing optimized innovative transportation parameters and solutions minimize investment and operational costs for a given flow rate; at the same time considerations on structural reliability for the "overall cycle" of a pipeline (from the design stage, material procurement, logistic issues, build up phase, gas in, operational & maintenance, contingency issue, till the final decommissioning) is the greatest concern as crossing harsh and sometimes "unknown" environments can constitute an extremely high risky condition for a "new" option. At the same time, only innovative solutions can make economically viable the exploitation of challenging gas reserves, located in remote areas.

Designing a long distance pipeline (to transport large volumes of natural gas over the entire design lifetime) through technical-economical optimization involves complex and interacting process, by means of iteration processes to get an established target value by minimizing the overall costs (investment plus operation) over target lifetime reliability. This target function comprises the component costs, to be multiplied by the needed quantity (the overall pipeline steel tonnage or the number of turbo-compressors units). Instead the required quantities for each specific project can be evaluated through a global gas transportation asset analysis (route altimetry, pipe diameter, design pressure, inlet and outlet compression ratio, gas speed, recompression span length). Furthermore, cost of materials, of handling and transportation to the site, of surveying, of construction equipment and works, of pre-commissioning and operation, of inspection and maintenance is depending on the specific requirements applied by the pipeline operator; most of them are function of the location of the project.

For short length pipelines the pressure drop due to frictional losses is small, so that compression is not required. While for longer pipelines, once the pressure drops to a specific value then a re-compression stage is used to increase the pressure up to the level needed for the actual transportation demand, however below the MAOP (Maximum Allowable Operative Pressure). This process is regularly repeated along the pipeline. The key fact in developing long-distance pipeline is based on the nature & volume of the fluid, the pipe length, location and terrain and on the possibility to cut the cost to reduce pressure drops by increasing the operational pressure. However, along with an optimization process, the selection of the grade steel is a process variable and the usage factor depends on the grade and on each pipeline "homogeneous" sections (due to use of the land, near to populated areas, environmental restriction).

As comparison among the different transportation options is made on reliability targets, problems could comes up when higher steel grades are taken in account, because only failure figures (from construction to operation) of common steel pipeline grade steels are currently available (up to X70).

So, there are only two ways to go on, either by desk studies involving literature reviews and performing sometimes strong assumptions or by performing testing as the most possible close as reproducing the "in the trench" conditions. Since the 1995, that last one has been the eni approach on the high strength steel projects for gathering natural gas over long distance at high pressure.

This paper is to highlight the framework of the TPI Research and Development project (*Trasporto Pressione Intermedia*, Intermediate Pressure Transportation) on High Pressure Natural Gas Transportation over Long Distance by using High Strength Steel Pipelines, aimed to collect/create all the necessary scientific background to perform reliable and precise techno-economical evaluations on the competitiveness of different pipeline transportation options.

Several pipeline steel grades were studied, as well as different pipeline manufacture routes; traditional and innovative construction (welding) processes as options for conventional and "harsh" conditions; a strong and efficient interaction with the worldwide pipe manufactures, contractors, consumable providers creating an "in kind" contributions as a "virtuous circle" was the engine of the project. Furthermore, the "winning key" issue has been the strong alliance with one of the most experienced Research Centers, with a 40 years long lasting competence on the integrity of components in gas pipeline industry; one of the very few in the world able to conjugate models development, lab testing, unique full scale facilities and the capability to “distillate” the achieved know how in user friendly manner.

eni has had a technical partnership with CSM since the mid of ‘90s. CSM was involved in an integrated framework of projects aimed to quantify the possibility to get direct experience through innovative testing and methodological options on High Strength Steel Pipeline for High Pressure Long Distance reliability overall cycle.

5) TPI Description

Since 2005, eni has focused its attention on the transport of gas at intermediate pressures (in the range 110÷130 bar) using grade X80 pipeline. The approach followed was similar to that used with success under the previous TAP (*Trasporto Alta Pressione*, High Pressure Transportation) project: an extensive use of full scale tests. Such activities were supported by both analytical studies and dedicated laboratory small scale tests programs. In addition to the technical topics studied in the TAP project for X100 grade steel pipes, the TPI project has focused its attention also on other specific aspects related to the design, supply of pipes, realization maintenance of a grade X80 line operating in hostile areas. The activity did not relate to a specific pipelines project, but it has been the point of aggregation of many results obtained by eni in the TPI and TAP projects, about the behaviour of higher grade pipes in relation to the various possible types of failures that may occur in the life of a line.
The first specific aim of TPI project was to develop specific know-how and tools for supporting the use of the “reliability-based limit state approach” (see Fig. 4) in the design of new high grade pipelines, as foreseen by the ISO 16708:2006. The interest was focused on pipeline grade X80 to be installed to permit service pressures >10.0 MPa.

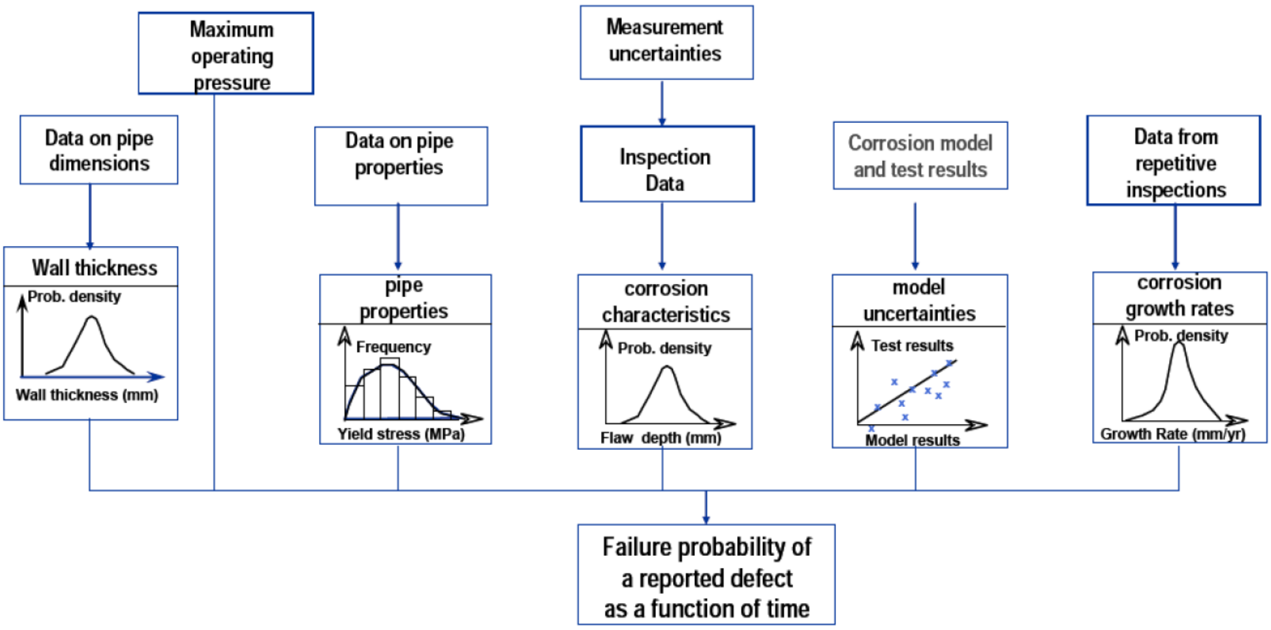

Fig.4. Input Parameters for Reliability-based Analysis

The improvement and verification of reliable constructionability of “in field” X80 grade line was the second technical topic addressed by the TPI project; specific items were the activities on the girth welds. In particular two specific issues were addressed:

- through a “in kind contribution” cooperation agreements with consumables providers, the “actual” market availability of welding consumables suitable for applications with proper requirements (mechanical properties for the welded joint both in terms of strength and toughness) was checked (see Fig.5);

- increasing the productivity of the root pass (thicker welded root throat and faster welding speed), see Fig.6.

Particularly on the last item an experimental activity was launched to verify the applicability to the first (root) welding pass on API 5L X80 steel pipes (OD 48” and WT of 22.4 mm), of a hybrid laser-arc head based on a commercially available bug&band system and performed in horizontal (as ASME - 5G).

	Pr.	Consumable 1	Consumable 2	Consumable 3	Consumable 4
UOE	GMAW	X	X		
	FCAW	X	X	X	
piral Welde Pipe	GMAW	X	X		
	FCAW	X		X	
	SMAW				X

Fig.5. Tests by using different consumable elettrodes

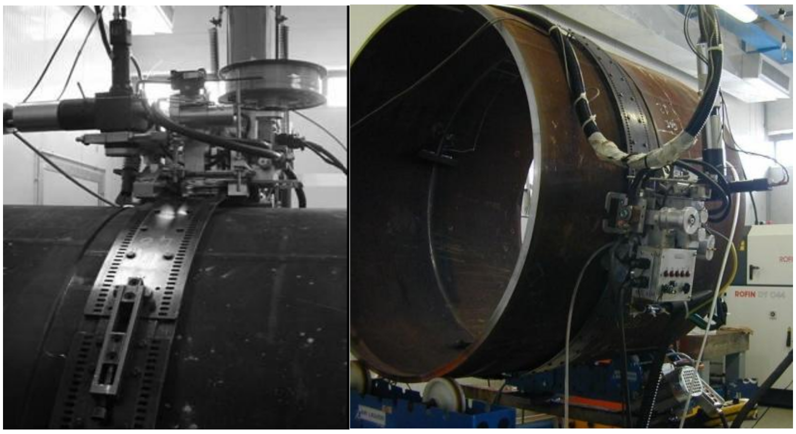

Fig.6a, Fig.6b. Hybrid Laser-Arc Head Based on a Commercially Available Bug&Band System

The strain design approach in the design of large diameter X80 grade gas pipeline was another topic studied in detail by the project TPI. It has been the development of know-how and experimental data for supporting the application of the X80 even in harsh environments, where the traditional “stress design” approach does not work and it is required also a “strain-based design” approach. To get this aim in a R&D project and to fully understand the full scale real behaviour of pipes and girth welds, a new full-scale bend testing facility devices and procedures to perform tests on large diameter/high grade (up to API X100) pipeline section of 30 m length were built and developed (Fig.7). That, at the end provided result to calibrate new tools for modelling the material behaviour and predicting the steel pipes performance.

Fig.7a. View of Bend Testing Facility

Fig.7b. View of a Pipe Section after the Bending Test

6) Conclusions

Independent evaluations proved that the pipeline option can be competitive for long distances, using high pressure gas transportation (unprecedented for land pipelines, while common for offshore pipelines) linked with high grade steel. More than one decade of Research & Development effort of Oil companies has been and is dedicated to the subject. eni started to investigate high pressure pipelines in the mid ‘90ies, in line with three decades of commitment on pipeline technology. In the last three years eni focused attention on topic concerning design, construction and operation of a gas transmission line operated at high pressure built with X80 pipeline steel; the impact on the issues of reliability and safety when using high strength steel was important to better evaluated the return on the investment on a “overall cycle reliability evaluation”. Key topics of the technical issues, were studied in different stages:

Design:

- the reliability analysis, data availability to perform based advanced design engineering criteria based on the design limit state,
- the specific design criteria focused on the strain design for extreme scenarios such as those subject to soil movement (landslides, permafrost, subsidence, etc..).

Construction improvements:

- the technologies of welding, both conventional and innovative (as hybrid laser-arc weld technology), for the fabrication of the line;
- the criteria for the definition of the tolerability of the defects in welded girth joints in high grade lines for high pressure;

Specifications requirements

- the additional requirements for the supply of high-grade pipes as a function of specific aspects of the project under consideration.

Operational

- the possible damage phenomena, both mechanical and arising from the interaction with the soil and/or cathodic protection, which over time can affect the reliability of a line in operation;

eni TPI project pointed out that X80 pipeline steel application can be considered well-established, as confirmed by extended new gas pipeline projects completion.

7) Acknowledgements

The authors wish to acknowledge the considerable contributions made by many colleagues of CSM and eni company, moreover a special thanks to all pipes manufacturers for their tangible support.

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