Medgaz: the ultra-deep pipeline
by Jay Chaudhuri¹ and Ian Nash²
1 Project Manager, Medgaz SA, Madrid, Spain
2 Project Manager, Intec Engineering (UK) Ltd, Knaphill, UK

HIGH-PRESSURE trunk lines have proved to be the safest, cheapest, way of transporting gas to the market for short to medium distances up to 2,500km, making the proposed ultra-deepwater Medgaz natural gas pipeline an economic solution for gas delivery to the Iberian Peninsula. Linking Algeria and Spain across the Mediterranean Sea for an offshore distance of 200km, the Medgaz ultra-deepwater gas transmission pipeline is designed to transport up to 16 billion cubic m of gas into the Iberian and European energy markets. When commissioned in 2008, the proposed pipeline will be well-placed to meet the demand for natural gas in the Iberian market, which is growing at annual rates of 17%. Internal and external studies indicate that the proposed Medgaz pipeline will enhance and ensure energy security for the Iberian Peninsula.

In June 2003, Intec Engineering (UK) Ltd was awarded front-end engineering design (FEED) of the Medgaz ultra-deep gas transmission pipeline from Algeria to Spain. The offshore portion of the pipeline route crosses the Alboran Sea in water depths greater than 2150m, and the design of the large-diameter pipeline included many project-specific challenges. Relevant issues include construction and maintenance in ultra-deep water, geo-hazards, and seismic risks associated with the continental shelf margins. Intec drew on its expertise on world-renowned projects, including BlueStream in the Black Sea and BP Mardi Gras in the Gulf of Mexico, to deliver a safe, installable and optimized design for the Medgaz pipeline system.

The paper details the design, operation and environmental considerations which have governed the project development strategy to date.

Background requirements for gas in the Iberian Peninsula

Iberia's fast-growing energy market poses challenges to the existing infrastructure. Spanish gas consumption alone has grown from 21.4 billion cubic m in 2002 to 28.3 billion cubic m in 2004, and it is estimated that annual demand will exceed 44 billion cubic m in 2011 (Fig. 1). Manufacturing growth and the need to switch to friendly fuels, as dictated by the Kyoto Protocol, is increasing gas demand by an estimated compound rate of 17%/yr. In contrast, the available system capacity is barely managing to keep pace with the growth in demand, resulting in gas supply shortfall in peak winter periods. To meet this shortfall, a number of gas-infrastructure projects are currently under way; however, it is anticipated that peak capacity shortages, which are currently being experienced in Spain, will stretch to at least 2010 (Fig. 2). Delays in increasing the gas and power infrastructure capacity could harm the fast-growing economy of the region and the development of the Iberian energy market in the short- to medium-term.

The long-run marginal cost (excluding producing country royalty) for potential gas supply to Spain has been studied extensively by independent energy consultants OME and Wood Mackenzie. These studies indicate clearly that the proposed Medgaz gas pipeline will be the lowest-cost supply option for Spain (Fig. 3), resulting in clear

Fig. 1. Spanish gas system capacity (source: CNE 2004).

This paper was first presented at the Deepwater International 2005 conference held in London on 8 April.
Medgaz project overview

The Medgaz project was initiated in 2001 by CEPSA and Sonatrach. Since then, the partnership has grown to seven members, as shown in Fig. 4.

The gas supply system in its entirety consists of 500-km, 48-in diameter, onshore pipeline in Algeria that will be owned and constructed by Sonatrach, and which connects to the offshore Medgaz pipeline at Sidi Djelloul in Algeria, where the Beni Saf compressor station (BSCS) is located. The Medgaz pipeline system consists of two 24-in diameter submarine pipelines, each 200 km long, which cross the Mediterranean (Alboran Sea) from Sidi Djelloul, Algeria, to Almeria, Spain. The maximum water depth experienced along the route is 2155 m. At the offshore pipeline receiving terminal in Almeria (ORPT), connection is made to the 48-in diameter Spanish onshore pipeline, which will be owned and constructed by others, to connect into the Spanish grid.

The Medgaz project covers the BSCS, ORPT, subsea pipeline, and two short onshore sections of high-pressure pipeline which connect the submarine pipeline to the compression and receiving facilities, respectively. The pipelines, when installed, will have the capacity to supply 16 billion cum/yr to the Iberian Peninsula and European grids by directly connecting Algerian gasfields and the Spanish gas network (Fig. 5). A schematic of the subsea pipeline crossing of the Mediterranean is given in Fig. 6.
**Technical data and design constraints**

The design life of the Medgaz pipeline is 50 years, with a total system throughput requirement of 16 billion cum/yr. This throughput, however, is only required in year 15, with a proposed build up from 6–8 billion cum/yr over the first five years. Based on this stepped increase in throughput, a phased approach has been adopted for the two pipelines. Phase I will be the construction of the easterly of the two pipelines plus the short onshore and shore approach sections of the westerly pipeline; the civil works for the compressor station at Beni Saf and receiving terminal near Almeria in Spain; the compressors and associated facilities for 8 billion cum/yr capacity with three compressors in service (2 LP and 1 HP). Phase 2 will be the construction of the second submarine pipeline (the west pipeline) connecting the pre-installed shore approach stubs of the Sidi Djelloul and Almeria landfalls, plus the installation of a further two compressors (1 LP and 1 HP) at the Beni Saf compressor station to raise the throughput to 16 billion cum/yr. The development throughput is summarized in Table 1, and the design parameters for the terminals and the short onshore and offshore Medgaz pipelines are shown in Table 2.

**Marine surveys and geotechnical information**

To meet the demanding requirements of the ultra-deep Medgaz pipeline, extensive marine surveys were performed during 2002-2004, commencing in June, 2002, with an initial survey performed by C&C Inc to gather information on bathymetry, seabed features and soils, which allowed the selection of a potential pipeline route. Based on the selected initial route for the pipeline, Fugro BV performed a geotechnical survey in July and August 2003, and collected detailed information on the nature of the sea bottom and soil characteristics along the pipeline route. This survey also investigated hazards identified by the Phase I Study by Snamprogetti SpA and CSIC. This was followed in August

<table>
<thead>
<tr>
<th>Year</th>
<th>Flow (billion cum/yr)</th>
<th>No. of pipelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>16</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 1. Development throughput for the Medgaz pipeline.

<table>
<thead>
<tr>
<th>Pipeline design pressure</th>
<th>220bar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline max. temperature</td>
<td>60°C (upset)</td>
</tr>
<tr>
<td>Nominal max. temperature</td>
<td>50°C (normal)</td>
</tr>
<tr>
<td>Min. temperature</td>
<td>0°C</td>
</tr>
<tr>
<td>Maximum water depth</td>
<td>2155m</td>
</tr>
<tr>
<td>Approx length (offshore)</td>
<td>198km</td>
</tr>
<tr>
<td>BSCS inlet pressure</td>
<td>45bar</td>
</tr>
<tr>
<td>BSCS outlet pressure</td>
<td>200bar</td>
</tr>
<tr>
<td>OPRT inlet pressure</td>
<td>82bar</td>
</tr>
<tr>
<td>OPRT inlet temperature</td>
<td>0°C</td>
</tr>
<tr>
<td>OPRT outlet pressure</td>
<td>80bar (Spanish entry)</td>
</tr>
<tr>
<td>live crossings</td>
<td>5</td>
</tr>
<tr>
<td>Seabed Soils</td>
<td>Sand / Very Soft Clay (2-5KPa)</td>
</tr>
<tr>
<td>Seabed Slope</td>
<td>0-14°</td>
</tr>
<tr>
<td>Fault crossing</td>
<td>on Habibas Escarpment</td>
</tr>
</tbody>
</table>

Table 2. Design parameters.
through October 2003 with nearshore and onshore geophysical and geotechnical surveys by GAS srl.

The following geotechnical samples and tests were performed along the offshore route:

- 65 piston core samples
- 15 box core samples
- 25 cone penetration tests (CPT)
- 5 in-situ vane tests
- 5 T-bar tests
- 10 seismic cone penetration tests (SCPT)
- 15 seawater samples

The main findings from the geotechnical survey were:

- slope and deepwater areas are composed of mainly soft or very soft clays, with no volcanics or turbidites
- no evidence in sediment cores
- of recent soil mass movement
- no evidence of hydrogen sulphide gas, mud volcanoes, or mud flows

In 2004, two further surveys were performed to complete the detailed understanding of the route and its features. These included an ROV/
AUV detailed geophysical survey performed by Geoconsult AS (May-June, 2004) and a high-resolution multi-channel seismic survey performed by Fugro Survey Ltd (June, 2004). Specifically, these surveys were designed:

- to acquire high-resolution bathymetric and geophysical data in the abyssal plain and the areas not covered by previous survey. The total survey distance was 521 km;
- to locate and accurately map five live submarine telecommunication cables at proposed crossing locations;
- to acquire visual data at points or regions of interest along the proposed route to support engineering interpretation and environmental baseline assumptions;
- to collect 24 seabed samples in support of the benthic classification studies (Fig. 7);
- to further define the character and impact of near-seabed faulting in areas at the crossing of the Yusuf Fault and potential faults on the Spanish Slope and Abyssal Plain, (using a 96-channel/160-cuin source array multi-channel equipment over 623 km and 15 lines) (Fig. 8);
- to perform a magnetometer survey on the continental shelves from water depth 20 m to 250 m.

Design of the marine pipeline

Routeing and geohazards

The information provided by the survey campaigns permitted selection of the optimum pipeline route to meet the following objectives:

- minimization of environmental impact
- protection of marine flora/fauna on the offshore and onshore sections on the Algerian and Spanish sides
- avoidance of natural obstacles that exist along the route

Fig. 10. Pipeline profile and morphological features.

Fig. 11. Bathymorphological characteristics of the pipeline route.
*low geological and geotechnical risks
*minimal number of cable crossings
*ensuring the feasibility to employ S- and/or J-layer construction methods
*minimization of "free-span" risks

The resulting pipeline route from landfall to landfall has a route length 198.3 km and reaches a maximum depth of 2155 m approximately midway along the route, with approximately 50% of the pipeline having depth greater than 1000 m. In total, the route is described by 19 changes in direction and crosses five live telecommunications cables, all depths greater than 1800 m. The proposed route is characterized by a geological fault crossing known as the Yusuf fault, located on the upper Habibas escarpment at approximately KP62, and steep slopes (around 14°) between KP71 and KP77 on the lower Habibas escarpment. The pipeline route and details of the slopes along the route are presented in Fig. 9, and the profile of the pipeline is presented in Fig. 10.

**Geohazard evaluations**

The initial results of surveys and technical studies performed by CSIC characterized the bathymorphology of the pipeline route (Fig. 11). Based on the known characteristics of the pipeline route and information available from the surveys, detailed geohazard assessments were performed to ensure the proposed pipeline route avoid significant geological and seismic risks. These assessments included:

- geophysical interpretation
- probabilistic seismic hazard assessment (PSHA)
- slope stability assessment

**Fig. 12 (above). Finite-element analysis of buckling collapse.**

Wall thicknesses were calculated to meet internal pressure containment, pressure collapse, and local buckling during installation. An additional requirement for wall thickness was to achieve a minimum specific gravity of 1.1 for the pipelines without weight coating. The calculated wall thicknesses ranged from 22.9–29.9 mm, depending on water depth; the distribution of wall thickness requirement and selected wall thicknesses along the pipeline route are presented in Fig. 13.

**Fig. 13. Wall thickness and buckle arrestor distribution along the pipeline route.**

- probabilistic fault displacement hazard analysis
- numerical runout modelling

The geohazard assessments showed that the steepest slopes encountered at the Habibas escarpment (KP71–KP77) will not affect pipeline stability and long-term operation, and that the critical slopes of the route are stable for seismo-tectonic events with return periods of greater than 475 years. The design of the pipeline is demonstrated to be extremely robust for safe operation in conceivable earthquake conditions.

**Wall thickness and buckle arrestors**

Critical to the success of the Medgaz project is the selection of wall thickness to withstand the immense external pressures during installation. At the commencement of the FEED, verification to confirm the adequacy of the DnV OS-F101 formulations was performed using ABAQUS generalized finite-element modelling software to simulate local buckling and subsequent propagation under typical installation loading conditions (Fig. 12). Cross-checks were made with physical collapse data available from Bluestream, Oman-India, and various Gulf of Mexico ultra-deepwater projects. Good correlation was found between the finite-element collapse models, physical collapse data, and the DnV formulations, which allowed the project to conclude that the use of DnV as a governing code was both safe and optimal with respect to minimizing wall thicknesses.

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**Fig. 14. Buckle arrestor cost vs spacing.**
In order to mitigate buckle propagation, buckle arrestors are required in water depths greater than 339m. As both S-lay and J-lay vessels are envisaged as potential installation candidates, it was necessary to design both short-collar and long-pipe buckle arrestors. In the case of long-pipe buckle arrestors, wall thicknesses in excess of 50mm are required to meet the DnV formulations. Wall thicknesses of this magnitude are outside the range of UOE linepipe; the number of buckle arrestors was therefore minimized whilst maintaining an acceptable level of spare pipe contingency. Figure 14 details the economic cost evaluation versus buckle-arrestor spacing performed to determine the selected 1960m centre-to-centre spacing.

**Stability, protection, and intervention**

Seabed currents on the continental shelves in both Algeria and Spain require that the pipeline has 2400kg/m³ density concrete coating for stabilization, of 80mm thickness to a depth of 40m, and of 45mm thickness to 250m. However, as numerous evidence of deep trawl scars had been observed to depths of 540m in the 2004 survey the concrete coating was extended to 550m water depth to protect the pipeline against fishing interaction.

Other forms of intervention along the pipeline route for both pre-lay and post-lay are required for the following purposes:

- stability at the Algerian and Spanish landfalls
- above-water tie-in
- thermal buckling prevention and remediation
- free spans exceeding allowable lengths and heights
- fishing interaction
- crossing requirements

These intervention areas are summarized in Fig.15.

**Crossings**

The pipeline route crosses five in-service telecommunications cables and 12 out-of-service telecoms cables. All the in-service cables are in water depths greater than 1800m,
and were observed in the 2004 surveys to be fully exposed on the seabed. In water depths greater than 1000m, bottom-exposed structures are not considered to be at risk from bottom trawling, and therefore a simple bridge crossing, using concrete mattress piers on either side of each cable, has been adopted. The height of the piers will maintain a minimum separation between the pipeline and cable of 300mm when the maximum settlement in the soft seabed near the crossing is taken into account. A typical crossing analysis is presented in Fig. 16.

The complete pipeline route from Algeria to Spain has been analysed to determine the configuration of the pipeline in as-laid, flooded, hydrotest, and operating conditions, using Sage profile software. The analysis confirmed that an acceptable configuration was achieved under all conditions and that pre-lay intervention was not necessary. The analysis also highlighted areas where spanning was likely to occur and allowed a detailed assessment of post-lay intervention requirements.

The most significant area of spanning occurred on the continental slopes, most notably in the area where the pipeline passes through the canyons on the Habibas escarpment. A rendered image of this rough area is presented in Fig. 18. As this spanning area is in water depths greater than 1000m, and is characterized by slopes up to 14°, vortex-shedding strakes are an option for correction of spans.

In-service buckling

Elevated temperatures at the Algerian landfall and extreme water depths resulted in buckling issues both during hydrotest and operation. Initially, a Hobbs' analysis was used as a screening tool to determine areas subject to buckling and requiring more detailed assessment, and a typical screening plot for the operational condition is presented in Fig. 19. Once highlighted as potential areas for buckling, a detailed assessment of the area was performed by modelling the seabed and pipeline configuration in an Ansys FEM, which allowed assessment of the post-buckled condition.

In some areas, intervention to prevent pipeline movement and feed into buckles is necessary to prevent the pipeline from exceeding local buckling design code checks.

Installation assessments

Of primary concern to the project is to maintain installability by the widest possible number of candidate lay vessels. Currently, one 5-lay and two 1-lay vessels are considered to have the potential to lay the Medgaz pipeline. To confirm that the candidate lay vessels are capable and to establish limits on operability, detailed static and dynamic installation assessments were performed. The specific objectives of the installation assessments were to establish:

- the likely tension schedules and residual tensions in rough seabed areas
- that sagbend strains are consistent with values used to
Pipeline integrity assessments

Calculations were performed to assess the integrity of the pipeline under geohazard-type extreme failure events. The events covered included:

- fault slip: reverse, normal, and strike slip fault movement
- slope failure: failure of the steeper slopes resulting in loss of support to the pipeline
- mass sediment movements (turbidity flow and mud-slide events): impact of a fast-moving dense flow on the pipeline

The objective of these calculations was to verify the integrity of the pipeline, thereby ensuring pipeline survival during these extreme events. A typical strike-slip model is presented in Fig.21. A detailed finite-element analysis was performed on the section of pipeline between KP59.5 and KP63 using the seabed profile in this region. This region was selected because it contained Yusuf B Faults, which cross the pipeline route at various angles and which were highlighted in the seismic hazard assessment to be the main potential hazard for a surface-breaking fault along the route.

Fault/pipeline crossing angles between 45° and 90° have been examined in conjunction with fault-displacement hazard analysis to determine a safe crossing angle for the pipeline route, and the results of the parametric assessment of crossing angle and fault displacement are presented in Fig.22.

Environmental challenges

To minimize the environmental impact of phased construction, the shore approach sections of the Medgaz pipeline system will be built with the western (second) 24-in diameter pipeline installed with the eastern (first) pipeline during Phase I of construction. This approach allows for a single disturbance and reinstatement of foreshore and beach and will allow the second offshore pipeline to be constructed with no significant onshore construction activity in Algeria and Spain. The separation between the two offshore pipelines has been optimized to allow the width of the offshore corridor to be minimized while allowing sufficient space for the installation of the future second line.

The program of work is planned to avoid significant construction installation activities close to the coastal zones during the peak tourism periods of the summer months, and dredging and rock-dumping will be minimized to
reduce the disturbance of seabed flora and fauna.

The Medgaz project has also applied proven environmental principles for the design of the terminals. Some of the design features considered to minimize the environmental impact include:

- specification of dry low-emission turbines for compressor drives
- selection of BSCS compressor configuration for optimum fuel consumption at the projected gas-transportation rates
- use of air for actuation of BSCS valves
- use of flaring (instead of venting) during planned de-pressurization of either terminal
- specification of low-NOₓ burners for OPRT gas re-heaters

**Project schedule**

Intec completed the FEED for the Medgaz pipeline in mid-2004, and has continued to support Medgaz during the current post FEED 'Approvals' phase. The current schedule is for the EPIC tenders to be issued in the fourth quarter, 2005, with awards in the second quarter, 2006. The project has a first gas date of the fourth quarter, 2008. The current execution schedule is shown in Fig.23.

**Summary and conclusions**

**Technical summary**

The route selection is based on results of exhaustive geophysical and geotechnical investigation, which has minimized the project technical risks. The project has implemented the latest proven deepwater pipeline design and construction technologies to overcome the technical challenges, thus ensuring minimum transport costs for the proposed new route of gas supply to the Iberian Peninsula.

In-depth baseline studies and proven environmental principles have been adopted to ensure environmentally-friendly project implementation. In addition, the Medgaz project will contribute significantly towards the implementation of sustainable development strategies of an integrated energy plan for the Iberian Peninsula.

**Economic and commercial summary**

The Medgaz pipeline provides the most economic method of gas supply to the Iberian Peninsula and enhances the security of energy supply for Spain and Europe. It also promotes competition in the Spanish and Southern European energy markets and has been approved as a 'Quick Start' priority project under the EU TEN-E programme (Decision 1229/2003/CE).

On 12 January, 2005, the Spanish Government advised that priority rating A will be accorded to the project, ensuring project implementation to progress for first gas delivery in 2008.

**Acknowledgements**

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- C&C Technologies Inc
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- Fugro bv
- Fugro (UK) Ltd
- GAS srl
- Geocostal A/S
- Intec SA
- Intec Engineering (UK) Ltd
- JP Kenny Ltd
- Rambell A/S
- Snamprogetti SpA

**Abbreviations**

- BSCS: Beni Saf compressor station
- DnV OS: Det Norske Veritas offshore standard
- FEED: front-end engineering design
- FID: firm investment decision
- HP: high pressure
- LP: low pressure
- LRMC: long run marginal cost
- KP: kilometre point
- OPRT: offshore pipeline receiving terminal
- SAWL: submerged arc weld longitudinal

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