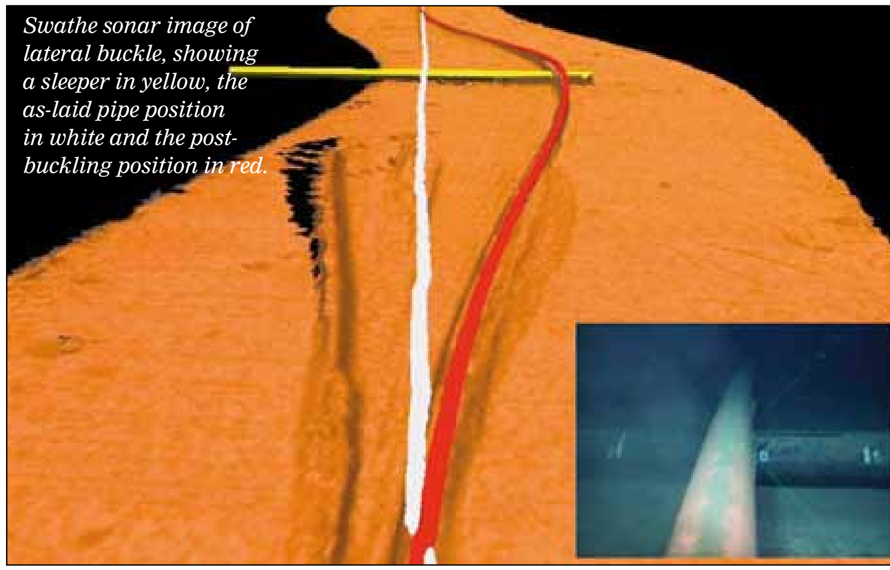
Bucking the trend

Deliberately designing pipelines to buckle – but in a controlled manner – is the Safebuck joint industry project team's recommended solution to today's ever more challenging deepwater pipeline requirements. And with most of the major operators already signed up for the JIP's third and final phase, it's clear the industry has taken heed. **David Bruton** and **Malcolm Carr** of Atkins Boreas explain



Swathe sonar image of lateral buckle, showing a sleeper in yellow, the as-laid pipe position in white and the post-buckling position in red.

As the oil & gas industry progresses into deeper water many new challenges have emerged. One of these is how to design and safely operate the pipelines that carry hydrocarbons from subsea wells to the processing facilities.

The main challenge is that these pipelines want to buckle due to the compressive forces created by internal pressure and temperature. Historically the offshore industry has trenched and buried pipelines to restrain them and prevent buckling. However, in deeper water, trenching and burying is less practical and with the higher pressures and temperatures often experienced in deepwater developments, this solution simply does not work. So what we now do is deliberately encourage the pipeline to buckle, but in a controlled way. By controlled initiation of lateral buckles at regular intervals, the loads are shared and reduced at each buckle site.

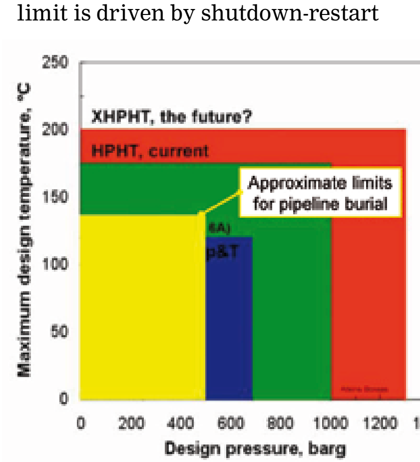
Early application of this idea has been hounded by problems due to a lack of know-how. This has led to a number of failures, including three full-bore ruptures and one abandonment, all due to the issue not being addressed correctly in design.

A related challenge is pipeline walking (gradual axial displacement of the whole pipeline with shutdown/restart cycles), which has been observed on a number of pipelines, in one case leading to system failure when the end connection ruptured. A number of walking pipelines have also required subsea intervention to prevent failures.

To address these new design challenges Atkins Boreas launched the 'Safebuck' JIP, which has received industry-wide endorsement (*OE* May 2007). Safebuck is funded by industry to carry out innovative research into all the key aspects of deepwater pipeline design and to formulate both design guidance and new design tools. The aim was to reduce risk by gaining more confidence in the design methods, and improve the feasibility of these challenging deepwater developments. The JIP assembled a world-class team of leaders in their field to contribute to the design guidance and research programmes.

Safebuck developed a design methodology for deepwater pipelines that encourages the deliberate formation of lateral buckles by pre-installing triggers at intervals along a pipeline. The JIP carried out ground-breaking research into:

(a) low-frequency high-stress fatigue in corrosive environments – this design limit is driven by shutdown-restart



The approximate limits for burial of pipelines.

About the authors

David Bruton is a senior advisor at Atkins Boreas, the centre of pipeline and subsea engineering expertise within the UK-based Atkins consultancy group. With more than 25 years' experience in the design, installation, commissioning and operation of oil and gas industry pipelines, he has managed a number of deepwater pipeline research projects and studies, including the Safebuck JIP, and provides specialist support to many current international deepwater projects.

Malcolm Carr was co-founder and technical director of Boreas Consultants, acquired by Atkins in 2007. He has been extensively involved in the design of HPHT deepwater pipelines and strain-based design, and provides technical leadership on the Safebuck JIP, undertaking research into the post buckling behaviour of pipeline systems.

The power of JIPs

David Bruton needs no persuading of the use and value of joint industry projects. Speaking to *OE* shortly after the announcement that Safebuck had secured the UKTI-sponsored 'Innovation and Technology Award' at February's Subsea UK conference in Aberdeen (*see page ??*), he said. 'Winning this award means a great deal to the JIP team.

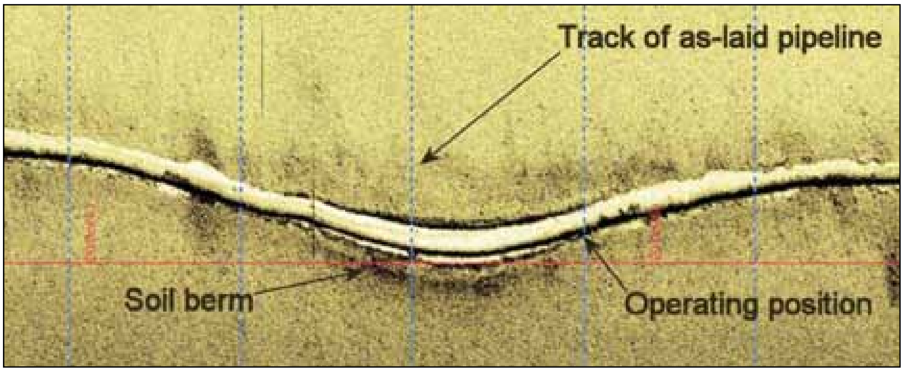
'We are extremely proud of the team and what we have achieved. It is incredibly rewarding to look back to the time when we struggled to get this JIP off the ground, trying to explain why we believed it was important, at a time when the industry was slightly cynical about the value of JIPs. However, we think Safebuck encapsulates the very best of joint industry project values. The work done has certainly proved to be important and represents a major advance in subsea pipeline engineering.'

The project team and supporting partners comprised Atkins Boreas, The Welding Institute, Cambridge University, OTM, Doosan Babcock, the University of Western Australia, NGI, Cathie Associates and Oxford University. Organisations, operators and contractors that have participated are: ExxonMobil, BP, ConocoPhillips, Statoil, the US Minerals Management Service, Petrobras, Woodside, Chevron, Shell, Total, Acergy, Allseas, Technip, Saipem, JFE, Tenaris and DNV.

cycles and is often the overriding design concern;
(b) local buckling of small diameter pipe – to establish safe design limits for the most popular types of pipe used in deepwater developments; and
(c) pipe-soil interaction to evaluate lateral and axial pipe-soil response – this is the largest uncertainty faced in design and was investigated with an extensive set of small-scale and large-scale tests, many in soils collected from deepwater sites.

The assessment of fatigue in a lateral buckle has highlighted a key concern because the fatigue loading is at incredibly low frequency (a few hundred cycles over a 20-year design life). This combination of low frequency, corrosive environment and high stress range means that fatigue lives are reduced by a factor of ten or more.

When it comes to pipe-soil interaction the JIP pioneered the idea of testing this response at very small-scale in a centrifuge where the g-force can be increased to compensate for the small model pipe diameter. The great advantage here is that the tests can be done much more quickly with much less soil than is used in tests at large-scale. Large-scale tests are still needed but the more we understand the simpler these tests will become.



Lateral buckle from seabed side-scan sonar.

Safebuck addressed these and many other significant design challenges for pipelines laid on the seabed that operate in the HPHT (high-pressure, high- temperature) regime, where the significant loads in the pipe must be controlled to avoid failure and ensure long term system integrity.

The JIP has received worldwide industry recognition, demonstrated by the high level of industry participation including most major operators and most major pipeline installers, together with the US government, through the Minerals Management Service (*see panel above*). The JIP has also been endorsed by the HSE in the UK.

DNV, whose design codes and recommended practices are internationally recognised, has also joined the JIP this year. It is keen to work with the Safebuck team on an industry-wide Recommended Practices to capture the design issues addressed by Safebuck, in the *DNV Recommended Practice RP-F114*, which already references work published by the JIP. This accords well with the intent of getting the JIP technology out to the wider industry.

Market penetration of the JIP technology is excellent, having been adopted by JIP participants for most current international deepwater HPHT developments in West Africa, the Gulf of Mexico, Brazil, Australia, the Caspian and in Indonesia. Many of these developments are now in production.

Most of the novel test methods developed for the JIP have now become industry accepted methods for project-specific testing. Also the lessons learned from this research have improved the way laboratory testing is done. A good example of this is the way Fugro brought 'the laboratory to the seabed' with its new Smartpipe deepwater pipe-soil friction measurement tool, which used lessons learned from Safebuck laboratory tests and has already been deployed offshore Angola.

The many papers published by the JIP are frequently referenced by industry authors and in designer's reports.

Large-scale pipe-soil interaction tests at NGI in Oslo.

Safebuck phase three

The key areas of work which will be undertaken in the Safebuck JIP's third and final phase are:

- verification of the reliability of the design methodology, with the aim of reducing unnecessary conservatism in design;
- collection and sharing of data and lessons learned from operating pipelines on recent projects without sharing potentially sensitive project specific data; and
- formalisation of the Safebuck design guideline into an industry Recommended Practice.

In addition, the key areas of work under the geotechnical scope are:

- development of a new 'force-resultant plasticity model' to run inside standard software packages, which will capture the JIP's considerable experience from modelling and testing lateral pipe-soil interaction. This approach is expected to fundamentally improve the way that lateral pipe-soil response is addressed in design; and
- a detailed review of axial friction response, based on recent project-specific tests, supplemented by additional JIP tests, to improve our understanding and quantify key uncertainties that influence cyclic expansion and pipe-walking.
- The aim of the work is to increase knowledge, and thereby reduce conservatisms, associated with the design process and related design limit states. The JIP is expected to be an enabling technology for many upcoming deepwater and HPHT developments.

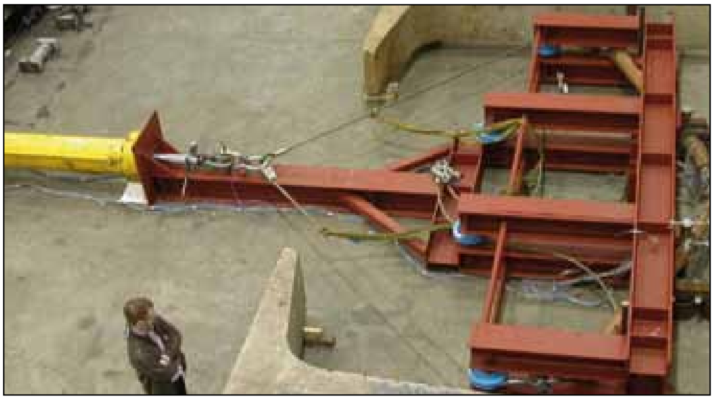
Meanwhile the JIP design methodology is an enabling technology for many current developments. Not adopting this design approach can be complex and costly; there are examples of projects employing in-line expansion loops along a pipeline with huge cost implications for the project.

The aim of the Safebuck JIP was to raise money from industry to support the development of innovative technology, including research testing and development of design guidance. In that aim, the JIP has been extremely successful, raising a total of £1.15 million to date, with anticipated funding in the final phase taking the total to about £2 million. The spirit of sharing knowledge and data within the JIP has also been exceptional, with participants donating data to a value of about £3 million in estimated research costs. So the value of technical information and data contributed to Safebuck far exceeds the total value of the JIP.

The development cycle for the current technology developed by the JIP is seven years (starting in 2002), which is well beyond any project timescale, again showing how a JIP can take the long-term view to help improve the way the industry does projects. Safebuck has also saved costs in a variety of different ways including shorter design times, avoiding over-conservative design solutions, reduced installation costs and mitigating against operational issues and potential failures, with the obvious impact on production losses and the environment.

The intellectual property generated by the JIP includes the design guideline, the research results and design software written for the JIP, which is licensed to each participant for use on their own field developments. The software and the evolution of the design methodology was a significant investment for the JIP and are fundamental to the acceleration of the project design process and schedule. The design cycle for such developments has reduced markedly over the duration of the JIP, reducing the key aspects of the engineering design cycle from years to months.

Indeed, recent projects would not have been engineered as quickly or with as much design certainty or future operational reliability without the Safebuck design methodology.



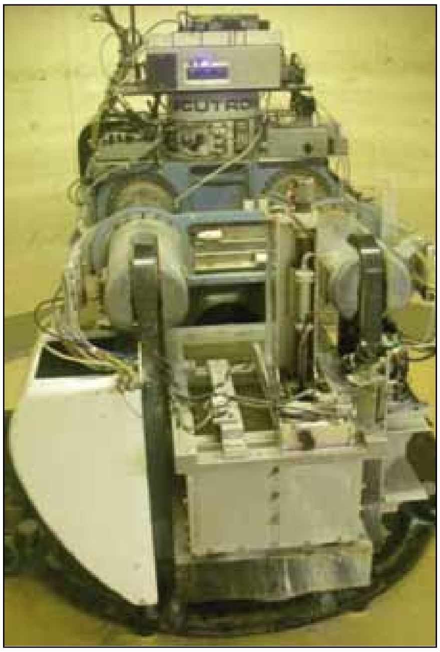
Local buckling test rig at Doosan Babcock.

The early adopters of the JIP technology were the companies that participated in the first phases of the JIP for their most challenging deepwater developments. Many of these developments are now in production and the integrity of their systems is being assessed against the same Safebuck methodology.

The recently launched phase three of Safebuck (*see panel above*) has raised a high level of interest and increased global penetration as the approach is adopted by companies that had not previously participated in the JIP.

One key aim in phase three is to collate performance data from operating pipelines that have been designed to laterally buckle, to improve our understanding of how they behave and better address the design challenges encountered on recent projects.

Another key aim is a major advance in pipe-soil modelling; this is so complex and critical to design that it desperately needs to be simplified and made more robust; the models Safebuck is are developing will be released worldwide to everyone involved in the JIP. **OE**



Small-scale pipe-soil tests in the centrifuge at the University of Western Australia.