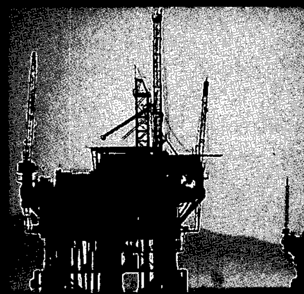

High Strength Steels - The Significance of Yield Ratio and Work Hardening for Structural Performance

MARINE RESEARCH REVIEW 9

MARINE RESEARCH REVIEWS

The aim of this series of short reviews, begun in 1993, is to disseminate the results of research programmes that were administered by the Marine Technology Directorate (MTD) beyond the immediate circle of the researchers and their sponsors to a wider readership in the offshore and marine industries.

The activities of MTD Ltd are now being carried out under the banner of a new company, CMPT, The Centre for Marine and Petroleum Technology Ltd. CMPT acknowledges the support of the Offshore Safety Division of the Health and Safety Executive in the production of these six reviews of research that has some implications for the safety and lifetime integrity of offshore structures. HSE was one of the contributors to each of the projects or programmes covered. Neither the Executive, the Division nor CMPT assume any liability for the reviews nor do they necessarily reflect the views or the policy of the Executive or the Division.

Six reviews have already been published, five of them with funding from the Oil and Gas Projects and Supplies Office (OSO) of the Department of Trade and Industry.

About the Offshore Safety Division

The responsibilities for regulating health and safety offshore were unified in a single body - the Health and Safety Executive - as a result of the recommendations of the Lord Cullen enquiry into the Piper Alpha disaster. A new Offshore Safety Division was set up as a result.

Research has played an important part in ensuring safety in the North Sea and will continue to do so. A major aim is to undertake an integrated programme of projects which address both the strategic or generic investigation of offshore hazards and the related short term needs, for example to support safety case assessment. A risk-based research strategy has been developed by HSE with input from the Division's Research Strategy Board to provide a means of prioritising research effort and helping to ensure that value for money is obtained.

About CMPT

CMPT is a new organisation set up to integrate research, innovation and technology for the upstream petroleum and marine industry. It will build on the capability and services of both the Marine Technology Directorate (MTD) and the Petroleum Science and Technology Institute (PSTI), each with its track record of meeting industry needs. CMPT's objective is to be the primary focal point and resource centre upon which its members rely for the provision of expertise and the facilitation of technology to enhance business performance.

Publications like Marine Research Reviews play their part in CMPT's technology transfer, delivering new technology from CMPT research programmes into use.

High Strength Steels -
The significance of yield ratio and work-hardening for structural performance

by

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Contents

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AMEC Offshore Ltd
Amoco (UK) Exploration Ltd
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The ESAB Group (UK) Ltd
Health and Safety Executive
Norwegian Petroleum Directorate
Shell UK Expro
Total Oil Marine
Texaco Britain Ltd.

The authors of this review were also the researchers on the project, and the series editor is Judith Mirzoeff. Members of MTD may consult the full research reports in the MTD library. Part of the work described here is also included in the MTD publication *High strength steels in offshore engineering* (Ref. 95/100) which is priced at £55 to non-members (£40 to members). Anyone interested in taking up the described techniques should contact the researchers or the programme manager:

Further information on the programme is available from:

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Note

The Offshore Safety Division of the Health and Safety Executive has supported publication of this report to encourage dissemination of the results of research that has received public funding. This support does not imply automatic endorsement by the HSE of any of the technologies described.

Summary

Considerable interest is being expressed in using higher strength steels with yield strengths of 450 MPa and above in offshore structures. Over the past five years or so, such steels have achieved an average utilisation by weight of 25%, with levels of 50% and above in more recent structures. This is supported by a greater appreciation of their benefits in terms of weight/cost reduction and by a more widespread demonstration of their superior mechanical properties, weldability and satisfactory fatigue performance. Several manufacturers can consistently deliver high quality high strength structural steel plate to satisfy current offshore material specification requirements. These factors, taken together, encourage greater confidence in considering such steels for structural applications, even in key jacket components. However, there remain some concerns related to the deformation capacity of modern higher strength steels. Such steels possess different stress-strain characteristics from lower strength steels as indicated by their higher yield strength to ultimate strength ratio values and there is an associated implication of reduced safety and conservatism in design.

This review summarises the findings of a study carried out at Cranfield University over the period 1992 - 94 to generate an awareness of these concerns and evaluate the significance of yield ratio and changes in work hardening capacity in relation to structural performance. The reasons behind these changes in steel behaviour are identified and the impact on design approach and suitability of current code provisions is assessed. New information is presented that supports the specification of higher strength steels and provides grounds for a re-appraisal and broadening of the scope of current codes and design rules, which would ensure their safe, efficient and cost-effective use in future offshore construction. Finally, the study identifies areas where further work is required in order to provide the necessary supporting information to carry out a revision of design codes.

Introduction

With the continuing expansion of oil and gas exploration into remote, deeper water and lower temperature regions, the specification of steel requirements in terms of mechanical properties and weldability has become more demanding. Over the years, offshore structures have increased in size and weight, the most significant factors which determine a jacket's weight being topside operating weight and water depth. Because a large amount of steel is consumed in construction (typically up to 25,000 tonnes in modern fixed platform structures) low material and fabrication costs are additional important criteria that influence the choice of material[1-6].

The recent development of marginal fields in shallow waters has followed a minimum facilities philosophy in terms of both the platforms themselves and their processing equipment. Allied to this over the past five years or so, with the evolution of heavy lift crane barges, lift-installed platforms have become increasingly attractive in preference to barge-launched platforms[3,7]. This has brought about considerable effort to minimise structural weight by optimising structural design and platform layout. In this respect the choice of steel can play an important role. Generally, weight reduction is achieved by the use of higher strength plate, enabling plate thickness to be reduced. However, it is important to realise that mechanical behaviour will also limit the allowable minimum thickness, and thus the possible weight reduction. As weight approaches the critical lifting limit, weight rationalisation becomes of paramount importance.

Most structures contain significant quantities of weldable structural steel of yield strength around 350 MPa, conforming to BS7191 Gr 355. Several studies have illustrated the weight-saving potential of modern higher strength steels. For example, in topside design, by substituting a 500 MPa steel in place of a conventional 350 MPa steel, a 25 to 30% reduction in weight is predicted[6,8-11]. This is significant in itself, but weight saved on topside has a knock-on effect by reducing material requirements in the supporting jacket[1,3,9]. In addition, there is considerable associated saving in fabrication costs as a result of the reduction in the amount of welding required. The price premium on a modern grade 450 MPa steel compared with a 350 MPa steel is of the order of 10 to 15%, depending on thickness, which is more than offset by the reduced steel tonnage consumed[1,11]. One operator estimated that the resultant saving of some 700 tonnes on the topside and the lesser amount on the supporting jacket structure in a single project reduced the direct costs by some £1M[12].

As a consequence of systematic steel development and assessment over the past 20 years or so, there is a growing body of knowledge of and experience with higher strength steels with respect to properties such as strength, toughness, weldability and fatigue, which lends significant support to promoting their suitability to meet current offshore requirements[1-6,12-21]. Taken together, these factors emphasise the considerable operational and cost benefits to be gained by the use of higher strength steels. Indeed, the present study has shown that there is a somewhat limited but increasing demand for high strength steels offshore in the strength range 400 to 600 MPa. Typical tonnages used in modern fixed platforms are in the range 20 to 50% of total weight, primarily in topsides but also more recently in the jackets themselves[1,22]. These materials are being adopted in all structure types and under suitable conditions they will certainly find increasing future usage in a wider variety of offshore applications.

Of course, steels in this strength range have been used for many years in subsea pipelines where API X65 and X70 grades (446 MPa and 480 MPa) have been widely used. Quenched and tempered steels of even higher strength, up to 700 MPa, have been used for many years in the construction of mobile jack-up rigs[1-11]. Defence-related projects worldwide are also actively pursuing the potential of modern high strength steels up to 690 MPa for submarine and surface vessel construction[15]. Despite this experience and incentive for their use and the fact that many of the early concerns such as weldability and fatigue have, to some extent, been satisfied, higher strength steels have not been more generally adopted in fixed offshore structures, due to several factors discussed below.

In addition to the understandable inherent conservatism in the oil and gas industry, the further application of these materials is often limited by a lack of detailed and up to date information and knowledge among potential users. Several large research and development programmes are under way to remedy this situation[2,13,16,17-20]. Recently, more fundamental areas of uncertainty have arisen with respect to designing with higher strength steels, related to their work hardening behaviour. Generally, such steels possess different stress-strain characteristics from conventional lower strength structural steels and some designers argue that the safety margin in design is being eroded. Furthermore, current specifications and design codes can severely penalise the use of higher strength steel in some cases by placing limitations on allowable design stress or maximum strength grade included in such specifications. These limitations can together negate the benefits of specifying higher strength steels in the first instance[1,22,23]. While material and welding technologies have advanced over the years, material specification and structural design codes have not developed at the same rate to provide rational and comprehensive guidance for the efficient and safe use of these materials[1,5]. Given the increased interest and potential value of high strength steels in offshore applications, it is now vitally important to review the design codes to ensure that they fully consider these steels.

This review summarises the findings of a study in the MTD Managed Programme *High Strength Steels in Offshore Engineering* at Cranfield University over the period 1992 - 94 to generate awareness of these particular concerns. The basic objective of the study was to establish data to enable the safe design of offshore structural components, particularly tubular joints, from higher strength steels.