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Strengthening, modification and repair techniques' prioritization for structural integrity control of ageing offshore structures

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ABSTRACT

Structural integrity control is vital for existing ageing as well as newly built offshore and onshore structures. Structural integrity control becomes highly sensitive to interventions under a potential loss of structural integrity when it comes to offshore oil and gas production and process facilities. This is mainly due to the inherent constraints present in carrying out engineering work in the offshore atmosphere. It has been further exacerbated by the ageing offshore structures and the necessity of carrying out life extension toward the end of their design service lives. Local and international regulations demand the implementation of appropriate strengthening, modification and repair plans when significant changes in the structural integrity are revealed. In this context, strengthening, modification and repair techniques such as welding, member removal/reduction of loading, mechanical clamping and grouted repairs play a vital role. This manuscript presents an approach for prioritizing the strengthening, modification and repair techniques using a multi-criteria analysis approach. An analytic hierarchy process has been selected for the analysis *via* an illustrative case. It also provides a comprehensive overview of currently existing; strengthening, modification and repair techniques and their comparative pros and cons.

1. Introduction

Structural integrity control (SIC) is an increasingly important element of the offshore engineer's role [1–3] and becomes vital when a structure has been utilized for a significant amount of time or beyond its designed service life [3–6]. In this context, the SI is defined as 'all of the structural aspects necessary to enable an industrial installation to function in accordance with stated duty *via* protecting health, safety, environment and quality (HSE&Q) performance requirements' [7]. SI inherently deteriorates due to 'ageing' of the existing physical assets. The term 'ageing' refers to the effect whereby a component suffers some form of material deterioration and damage (usually, but not necessarily, associated with time in service) with an increasing likelihood of failure over the lifetime [8]. The management of ageing assets is conventionally a challenging task, which requires various factors to be dealt with (*i.e.* damage, consequences, repair methods, safety, confidence, people, *etc.*) [3,9]. Moreover, confirmation of the provision of scientific facts that ageing assets are fit for service results in a positive impact on health, safety and the environment [10]. In other words, assessment of the SI of ageing structures helps to identify the potential restoration (*i.e.* strengthening, modification and repair) of elements within those structures [8,65]. In this context, strengthening, modification and repair (SMR) provides a backbone, ensuring SI and continued operation whilst assuring the HSE&Q of industrial installations. However, SMR requires rather different skills (*e.g.* welding, grouting, structural analysis, *etc.*) and knowledge, which are considered as specialists' work [65,11,12]. For instance, in the case of structures in offshore P&PFs, it is vital to plan SMR to optimize the high expenditure associated with offshore work. To date, deployed SMR schemes are inappropriate, unnecessary or expensive, mainly due to the lack of skills/knowledge [65,13]. Hence, the selection of optimal SMR schemes and individual SMR techniques is important for reducing in-service inspection.

Normally, a structural assessment is carried out to ascertain the requirement of SMR schemes. The structural assessment includes both platform analysis (to establish member loads or the resistance of the whole platform to design events) and code or other checks on the (intact or damaged) component capacity [14,15]. Once the necessity for an SMR scheme/individual techniques is confirmed, then a decision on optimal SMR techniques could be based on criteria such as technical performance, reliability, costs, depth limitations, offshore support requirements, existing applications, extent of background knowledge, timescales for design/fabrication/installation, tolerance acceptability, post-installation

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inspection requirements, potential problem areas, remaining life of installation, environmental and other legislative requirements, and operator preferences [11,5,16]. However, the selection of an inappropriate method results in wastage of time and adverse effects on environmental, economic, health and safety aspects [9,17]. Therefore, it is essential to make the right decision on SMR techniques in a selection process with the aid of expert judgments.

This manuscript suggests the use of a multi-criteria analysis (MCA) approach for the selection of the optimal SMR techniques to cut down wastage in terms of cost, time and adverse effects on environmental, economic, health and safety aspects [18,19]. The analytic hierarchy process (AHP) is suggested mainly because of its inherent capability to handle qualitative and quantitative criteria simultaneously within the context of operations, maintenance and integrity control of oil and gas (O&G) production and process facilities (P&PFs) [17,19–22]. In addition, the AHP prioritizes relevant criteria and develops a consensus for making balanced decisions within the context of the physical assets' integrity control [22–25]. Furthermore, the hierarchical structure suggested for utilizing the AHP approach aids in the systematic visualization of the industrial challenge [19]. This enables a team of engineering experts to make comparisons based on each potential hierarchy and determine the priorities based on the criteria and sub-criteria along the structure in evaluating the alternative technical solutions for maintaining the SI.

2. Industrial challenge and candidate SMR techniques

For offshore structures, the selection of the optimal SMR is an important aspect in ensuring the safe continuation of the production and process facilities' operations. However, the selection process remains a challenge as it requires knowledge of the available range of techniques, including variants, their strengths and weaknesses, and an appreciation of other factors such as ease of design, buildability, offshore support and equipment requirements, local supply infrastructure, regulatory requirements, *etc.* In particular, the O&G industry operating on the Norwegian Continental Shelf is required to satisfy many stringent requirements during the operation and life extension of the existing structures [17]. In this context, maintaining SI during the extended lifetime of an installation is also an essential task. To restore the SI, structural assessments of components/structures are performed to identify the requirement for SMR [8,65]. Hence, SMR plays a vital role in ensuring safe operations by performing effective maintenance of industrial installations.

Once the local or global SMR has been recognized, the corresponding structure needs to be reanalyzed in relation to the SMR scheme/technique to ascertain whether the required level of SI would be reached or not. In essence, SMR techniques are classified into welding (*e.g.* dry or wet welding), use of clamp technology (*e.g.* use of mechanical clamp, grouted clamp/sleeve), grout filling of members or joints, weld improvements (*e.g.* toe grinding) or other techniques (*e.g.* members' removal) [65,11]. Fig. 1 illustrates the available SMR techniques.

It is also important to take into account various criteria such as technical performance, reliability, costs, depth limitations, offshore support requirements, existing applications, extent of background knowledge, timescales for design/fabrication/installation, tolerance acceptability, post-installation inspection requirements, potential problem areas, remaining life of installation, environmental and other legislative requirements, and operator preferences, *etc.* However, this poses a significant challenge for practicing engineers to make such decisions by taking both quantitative and qualitative information into consideration. For instance, Table 1 compares the different SMR techniques and their

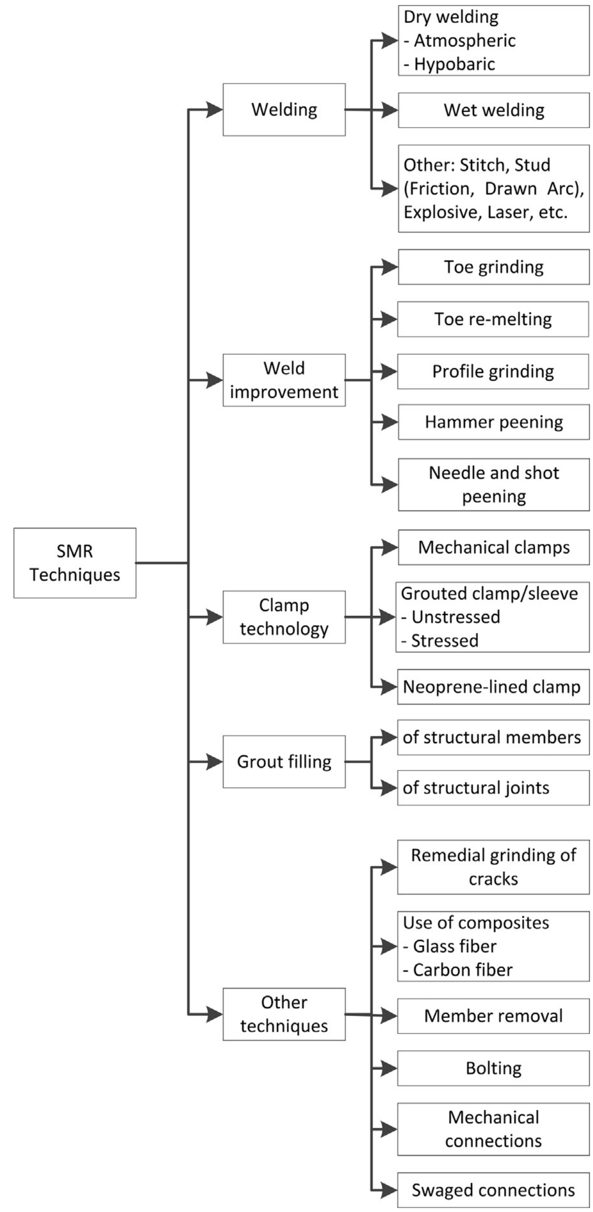

Fig. 1. Available SMR techniques.

installation cost, time taken for installations, *etc.* Table 2 indicates the potential applicability of SMR techniques for the selected defect scenario.

2.1. Interrelationship of SMR techniques

In the evaluation of SI and fitness-for-purpose, engineering/technical assessments and reliability assessments play a vital role. The reliability assessments are classified into three levels on the basis of approximations made [26]. Essentially, if complete knowledge about the full distribution of all relevant variables is available, then it is possible to perform exact probabilistic analysis approaches (*i.e.* called level III). However, on most occasions, the possibility of using such approaches for offshore structures is minimal due to the lack of data and information about important variables. Hence, idealizations are suggested in order to cater for the inherent nature of the data and information about offshore structures (*i.e.* called level II) [26]. For instance, the statistics of the basic variables are only described in terms of average values and variability, whilst neglecting the variation of less important