Mortarless Construction Using Umbilicals

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Abstract

Various facilities in the Northwest shelf off Western Australia are due to undergo decommissioning. This project seeks to apply decommissioned umbilicals in mortarless construction. Umbilicals are a type of flexible pipeline cable comprised of different components and layers, whose main purpose is to connect the host facility to subsea equipment's and provide electrical power, hydraulic supply, and chemical injection. Osteomorphic blocks use non-planar surfaces that interlock with each other. In order to hold the structure together and maintain its structural integrity an artificial constraint must be created between the blocks. It is thought that umbilicals have properties which can create the required artificial constraint between the blocks to hold them together. The umbilicals come from decommissioned offshore oil & gas production facilities and this application offers an opportunity to re-use them sustainably. Umbilicals also offer the potential for any beam or structure built with osteomorphic blocks to become a smart structure or a beam as umbilicals can provide electrical power and signals in addition to the required constraint. Tests will be performed to determine if the umbilicals can create the constraints to hold the blocks together.

1. Introduction

Offshore facilities use subsea wells, manifolds, and flowlines tied back floating production storage and offloading vessels. The objective of this project is to explore how the umbilicals from decommissioned oil & gas fields, and osteomorphic blocks can be combined to create a product that will have a commercial value. The umbilicals are combined with osteomorphic blocks to create smart beams or structures which can be used to transfer electrical power, data and signals. In the future these smart beams or structures could eliminate the need for a conventional wiring system in a structure. It is thought that the decommissioned umbilical's have properties which can create the required artificial constraint between the blocks to hold them together. The importance of this lies in both sustainably re-using the umblicals and creating an opportunity to be commercialized in the future to help the client generate revenue from the decommissioned umbilicals.

1.1 Literature review

Mortarless construction is a masonry construction technique that has been used for thousands of years and is continually undergoing refinements to achieve better structural performance, serviceability, and affordability (Hossain, et al., 2020). Dry stacking masonry refers to construction without mortar or any joint filler. This project is based on the research of Dr Dyskin and Dr Pasternak into the application of fracture resistant topological interlocking blocks with non-planar contact surfaces.

Topological interlocking is based on matching of non-planar surfaces of contacting elements forming a structure (Dyskin, et al., 2002). Topological Interlocking have special properties that in such assemblies the elements are locked within the structure by their geometric and kinematic constraints, provided that the assembly is constrained at its own edges (Dyskin, et al., 2002). The main feature of topological interlocking structures is that absence of physical continuity between elements lead to enhanced fracture resistance as cracks cannot spread from one block to another (Dyskin, et al., 2002).

Umbilical cables play a major role in deep and ultra deepwater oil and gas production systems (Guttner, et al., 2017). The purpose of umbilical cables is to connect the host facility to the subsea equipment providing chemical-injection, hydraulic supply, and electrical power (HeZhen, et al., 2012). Umbilicals are composed by different kinds of components wounded around a central core (HeZhen, et al., 2012)

Figure 1:Structure made with osteomorphic blocks (Dyskin, Pasternak & Estrin, 2012).

1.1.1 Osteomorphic blocks

This project focuses on mortarless structures built from osteomorphic bricks. The name osteomorphic references to the bone like shape of the blocks. Topological interlocking of the osteomorphic blocks occurs when the convex part of one surface of one element match the concave part of the adjacent element (Dyskin, et al., 2002). If the two surfaces are brought in contact, the XY plane of the structure can be kept in one place under the constraint in the Z direction. It’s very common that frictional forces are present between the contacting surfaces in any topological interlocking system, but they can be considered as a secondary effect compared to the resistance to displacement provided by the geometrical constraints (Dyskin, et al., 2002). Under a heavy load the concave parts of the surface might produce stress concentrations, but due to the smoothness of these surfaces the stress concentrations will be very mild compared to the ones that are produced by connectors in conventional interlocking bricks.

The non-planar surfaces of the osteomorphic blocks can be generated using the equations (Dyskin, et al., 2002).

$$z_1(x,y) = \Delta h\varphi(x)\varphi(y) + h \quad (1)$$

$$z_2(x,y) = \Delta h\varphi(x+a)\varphi(y) - h \quad (2)$$

$\varphi(x)$ is an arbitrary function satisfying the conditions of symmetry and periodicity as well the boundary conditions,

$$\varphi(x) = \varphi(-x),\ \varphi(x) = \varphi(x+2a),\ \varphi(0) = 1,\ \varphi(a) = -1,\ \varphi'(0) = \varphi'(a) = 0$$

The equation (1) and (2) are used to model the concave and convex surfaces of the block. As shown on Figure 2 the two faces of the blocks are modelled using the two period functions $z_1(x,y)$ and $z_2(x,y)$. The function $\varphi(x)$ should be periodic as it will allow the surface to be piecewise continuous which would create a smooth surface where the stress concentrations are negligible. If surface on the block is rough and pointy this would create stress concentrations on the surface, which would eventually cause failures when the blocks are put together. Figure 3 shows the difference between the surfaces when $\varphi(x)$ is piecewise linear and a piecewise continuous.

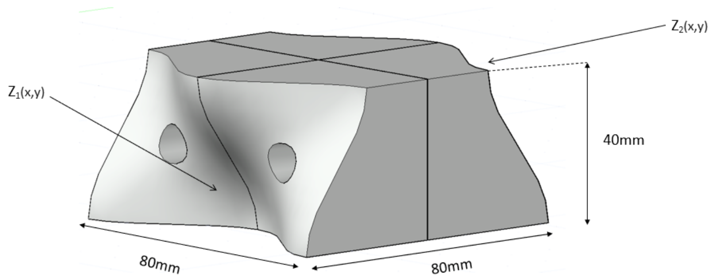

Figure 2: Osteomorphic block design

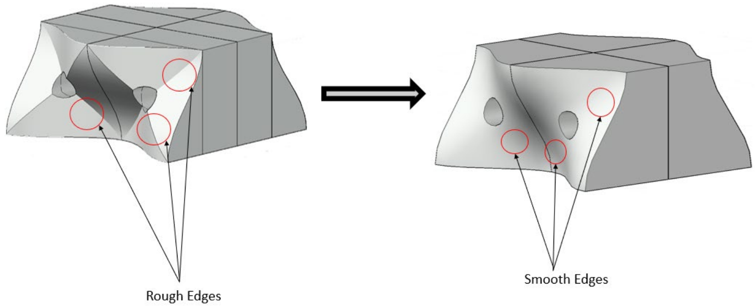

Figure 3: Piecewise linear and piecewise continuous surfaces of the block.

The osteomorphic blocks have been found to possess a range of interesting and useful mechanical properties. Damage tolerance, bending compliance, structural stability and energy absorption are some of the key properties enhanced due to the inability for cracks to propagate across the boundaries of the discrete constituent elements (Djumas, et al., 2017). Cracks cannot propagate from one block to another, and the structure maintains its integrity even if one or a large percentage of the blocks are missing or failed. Materials engineered in this way possess high fracture resistance and high damage tolerance.

Three types of primary sources of deformation and failure have been identified with the use of topological interlocking systems (Mirkhalaf, et al., 2016);

- Tilting of the assembly.
- Slipping or sliding of the assembly under concentrated load.
- Partial damage of the blocks near the interfaces.

1.1.2 Umbilicals

There are two types of umbilicals static and dynamic. Static umbilicas are used in fields which are relatively small where the depth varies from shallow to medium (Subseapedia, 2019). Dynamic umbilicals are used for complex applications where the cable must be placed in deep water.

Static umbilicals consist of steel tubes to deliver chemicals and hydraulic power to the subsea production system. Static umbilicals also contain one or more electric cables to deliver power and multiplexed signals to the subsea control system and carry back the instrumentation signals back to the host facility. The core is wrapped using tape and bundled and twisted into an umbilical, The taped umbilical is wound with high density polythene for more protection (Subseapedia, 2019).

In dynamic umbilicals the cables in the core of the umbilical are armored for more protection from the hang off point to the touchdown point and contain fiber optics in addition to the signal cables. Dynamic umbilicals are usually bundled with two or more layers of tape for protection (Subseapedia, 2019).

These are some major concerns with umbilicals (Subseapedia, 2019). Fatigue is a very common problem. Fatigue in umbilicals is caused mainly due to tube friction and vortex induced vibrations. A major concern with umbilicals is the plastic strain arising due to coiling the tubes in bobbins (and sometimes during installation and repair). Plastic strain also arises due to the tensile strength and hang off weight.

2. Methodology

2.1 Osteomorphic blocks and Umbilical Assembly

This project initially was going to use umbilicals as post tensioning cables to create an artificial constraint to hold the blocks together. Due to the COVID-19 shipment delays and logistical issues, the initial model was scaled down so that the designing could be started. Accordingly, an electric cable which has similar properties to decommissioned umblicals such as high insulation and a core with 3 or more wires has been used to simulate the umbilicals.

In the early stages it is important to carry out a full literature review on topological interlocking using osteomorphic blocks and subsea umbilicals. These allow to find all types of failures and concerns that need to be addressed in the design. The surfaces of the osteomorphic blocks need to be designed with no errors, as a single error can result a structure or beam to fail. A good literature review is important to minimise mistakes. The surfaces should then be designed to scale. The surfaces can be created by plotting the equations (1) and (2). It is important that these equations produce periodic results as it will allow the surface to be piecewise continuous. The points to be plotted can be generated using MS Excel. After generating the points, they need to be imported to a CAD software using the spline function to produce the surfaces. A fair amount of time should be allocated for the designing of these blocks due to their complex structures as many errors can be made in the drawing process. After designing of the blocks, it is very important to 3D print them, this will allow to check if the surfaces of the blocks are smooth, and the edges are curved enough. Once the blocks are 3D printed it is also easier to figure out if there are any stress concentrations on the surfaces. It is important that if there are any errors in the design tore-design the block and 3D print them again before making moulds.

Once the design of the block is finalised, the next step is to make the moulds for the block and design a mould assembly. After a health and safety induction is done for the workshop, the mould assembly process can start. As shown in Figure 4 the mould assembly will consist of 5 stainless steel osteomorphic blocks (80mm×80mm×40mm) with 2 half blocks placed in an acrylic nylon box with 2 stainless steel rods (10mm). After the mould assembly is manufactured the concrete/mortar will be poured into the moulds to create the osteomorphic blocks, with spacing for the cables to pass through later. It is important to leave the blocks to dry/cure for 28 days in a humidity room. While the blocks are left to cure, the next stage is to design and build a tensioning device. The tensioning device is the apparatus used to hold the cable and provide the tension to the cable to maintain the structural integrity. Also, an appropriate load cell which can measure the force would also have to be purchased. After the 28 days and when the blocks are cured, the blocks can be put together with the tensioning devices and the cable to create a beam. The next stage would be to perform the testing. 2 point and 3 point bending test will be performed to determine the flexural stiffness of the beam. After testing, the block can be modelled and analysed using finite element modelling to identify the regions of high and low tensile stress.

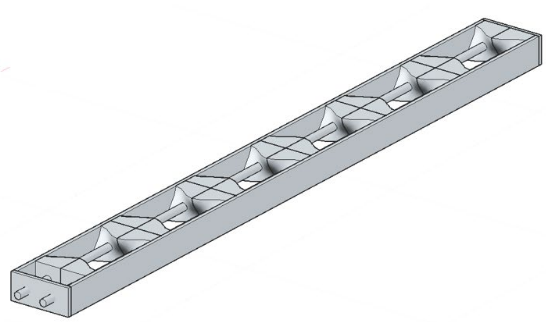

Figure 4: Mould assembly

2.2 Research Plan

The project consists of 4 stages, they are initiation, literature review, design, manufacturing, and testing. The project has progressed through the first 3 stages and currently onto the manufacturing stage. The last stage (design) had to be done with high accuracy as a small mistake could cause a huge error when casting the blocks and in the testing process. Using AutoCAD 3D and MS Excel the blocks were designed accurately to scale. Currently the project is in the manufacturing stage. The moulds for the blocks will be machined and built in this stage. Later, a mould assembly will be created which will allow the blocks to be casted. The concrete/mortar will then be poured onto the mould assembly which will allow the blocks to be made. In this stage a tensioning device will be designed and made for the blocks. A load cell will have to be purchased for the blocks. The next stage would be testing of the blocks which will be done 28 days after the blocks have been casted. The testing will include 2- and 3-point bending tests. Also, to achieve the key objectives of this project it is important to see if the cable can conduct electricity while producing the required constraints for the blocks.

3. Conclusions and Future Work

In this project the model used for testing had to be scaled down due to the logistical and COVID-19 shipment delays. It is yet to be determined whether umbilicals have the required properties to create an artificial constraint and hold a structure made with osteomorphic blocks together and maintain its structural integrity. In the future when Umbilicals are available, a valid model can be built by scaling up the model from this project and performing the required tests to find if umbilicals have the properties required to hold the blocks together and maintain the structural integrity.

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