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Parametric Study on Underwater Corroded Steel Pipelines Rehabilitated Using FRP and ECC

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Abstract: Offshore steel pipelines subjected to internal and external pressure undergo buckling due to axial compression. Retrofitting of corroded steel pipelines against buckling is necessary for their long life. The lightweight, high strength and corrosion resistance of Fibre Reinforced Polymers (FRP) make them ideally suited for quick and effective structural repairs of offshore steel pipelines. But FRP rehabilitation faces some disadvantages like brittle failure, debonding phenomenon, long term performance issues of composite structures etc. ECC as a composite material, have high ductility, durability, self-healing capacity, energy absorption capability and with multiple micro-cracks rather than localized cracks, thereby helps in preventing corrosion of steel structures. This paper presents an experimental study on ECC material properties and static analysis on different rehabilitated specimen using ECC, CFRP and GFRP. The analysis was carried out using ANSYS software.
Keywords: Offshore, Corrosion, FRP, ECC, Steel pipelines

I. INTRODUCTION

Repair of the offshore structural members will usually become necessary due to the marine environment and its effects on corrosion due to cyclic waves on the structure or impact damage from vessels or dropped objects. The degradation of the protective coating and formation of iron hydroxide is a result of the corrosion. FRP composites are widely used to strengthen, retrofit and repair offshore structures. The superior mechanical, fatigue, high strength to density ratio and in-service properties of FRP composites make them excellent candidates for strengthening and retrofitting of steel pipelines and infrastructure. There are several types of failure modes of debonding failures for FRPs such as end debonding whereby the detachment of FRP propagates towards the midspan of the structure. Engineered Cementitious Composites (ECC) is one of the composite identified for its superior durability, superior strain energy absorption and distinguishable high ductility. An attempt to overcome the premature failure ie., a remedy for CFRP debonding failure, has been done by incorporating ECC layer with FRP layers.

II. ECC AND FRP REPAIR SYSTEM

A. Engineered Cementitious Composite (ECC)

Engineered Cementitious Composite (ECC) also called Strain Hardening Cement based Composites (SHCC) or bendable concrete, is an easily molded mortar-based composite reinforced with specially selected short random fibers. ECC is a material with a high crack-control capability. The controlled crack width (typically below 100 lm) and self-healing capacity make ECCs an ideal material to improve serviceability and durability of underwater structures.

B. Fibre Reinforced Composite

Fibre Reinforced Polymer (FRP) composite is usually made of polymer/plastic matrix reinforced with fibres. FRP have been the ideal material choice for the rehabilitation of these tubular structures because of their lightweight, high strength and stiffness, good corrosion resistance and excellent fatigue properties. It consist of fibrous reinforcement like Carbon, Glass, Aramid etc. embedded in a polymeric matrix made of thermosetting resins such as epoxy or vinylestre. FRP materials are very lightweight, excellent corrosion resistance, high tensile strength, durable and flexible for application on any surface and it can overcome the disadvantages of welding or bolting in corroded structures. The use of fibre reinforced composites has already been proven effective for the strengthening and retrofitting of onshore and offshore structures.

III. EXPERIMENTAL STUDY ON ECC

Experimental study was conducted on ECC mix to obtain optimum percentage of PVA fibre with the cementitious and filler material. These material properties are used to input in ANSYS software for buckling analysis.

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A. Materials Used

ECC is made up of constituent materials which include Type-I Ordinary Portland Cement (OPC), Class F Fly Ash, 1mm thickness silica sand, poly-vinyl-alcohol (PVA) fiber 12 mm in length and 39 µm in diameter. A high range water reducing admixture containing a polycarboxylate chemical composition has been found to be most effective in maintaining the desired fresh property during mixing and placing.

B. ECC Mix Design

Table I gives a typical mix design of ECC (ECC-M45). In the mix coarse aggregates are deliberately not used because, the property of ECC includes formation of micro cracks with large deflection. Coarse aggregates increase crack width which is contradictory to the property of ECC.

TABLE I
ECC M45 MIX DESIGN PROPORTIONS[9]

Cement	Fly Ash	Silica Sand	Water *	HRWR*	PVA(%)
1	1.2	0.8	0.56	0.012	2

*Weight to cementitious materials ratio
HRWR- High Range Water Reducer

Fig. 1 ECC Mix Preparation

Fig. 2 Demoulded Specimens

All proportions are given with materials in the dry state with 2% volume fraction. Specifically, the type, size and amount of fibre and matrix ingredients, are tailored for multiple cracking and controlled crack width. ECC grade of M45 is prepared as in Fig. 1 by adding required amount of water and HRWR for finding the hardened properties of the specimens.

C. Hardened Properties of ECC

The fresh ECC mixture was cast in specific moulds for various tests, as listed in Table II. The specimens were then de-moulded after 24 hrs as shown in Fig. 2 and stored in a curing tank at room temperature.

TABLE II
SPECIMEN DETAILS

Test	Specimen	Size (mm)
Cube Compressive Strength	Cube	70.6x70.6x70.6
Split Tensile Strength	Cylinder	150mm diameter & 300mm height
Modulus of Elasticity		
Poisson’s Ratio		
Flexural Strength	Beam	100x100x500

The hardened properties of M45 ECC mix for 28 day strength with 2% PVA fibre content is listed in Table III.

TABLE III
HARDENED PROPERTIES OF ECC M45

Hardened Properties	Result
Cube Compressive Strength	51.1(N/mm^2)
Flexural Strength	7.1(N/mm^2)
Split Tensile Strength	6.9(N/mm^2)
Modulus of Elasticity (GPa)	28.58GPa
Poisson's Ratio	0.2
Density	1.98(g/cc)

IV. FINITE ELEMENT ANALYSIS

A Finite Element (FE) model was developed using the software ANSYS 17.2. The FE model tried to model the composite repair on steel structures in a simplified and practical manner so that the computational expense is minimised at the same time able to predict the buckling behaviour effectively.

A. *Materials Used*

A hollow steel pipe of 3m is modeled with 1.2 In thickness. The pipe was portioned into the corrosion region for 60cm in the mid span and thickness for this region was reduced by 20% as in Fig.3. The repair laminas were modelled using CFRP, GFRP and ECC. Adhesive layer modelled using Epoxy resin as an interface between the composite layers.

B. Material Definition, Boundary and Loading Condition

Seamless YST310 steel pipe is modeled and the corroded region was filled with filler material offshore polyurethane as in Fig. 4. The elastic properties of the repair laminas, defined based on the manufacturer is given in Table IV.

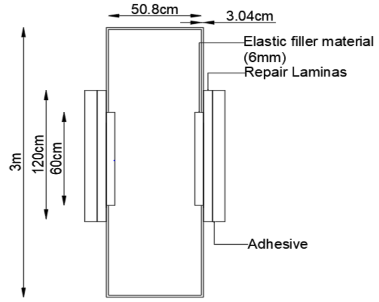

Fig. 3 Geometry for Composite Repairing

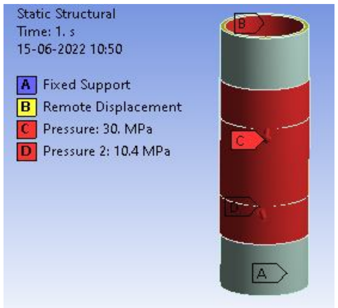

Fig. 4 Rehabilitated Specimen

TABLE IV
REPAIR LAMINA DETAILS

Lamina Type	Density (g/cc)	Poisson's Ratio	Elastic Modulus (GPa)
GFRP (Technowrap)	2.54	0.32	120
CFRP (Structural V-wrap)	1.54	0.4	276
ECC	1.98	0.2	28.58

The top support had the rotations free and the translations restricted except the translation along the axis of the pipe and the bottom support with fixed end condition. The loading was provided by an external pressure of 30MPa (3000m depth pipeline) and internal pressures of natural gas (10.4 MPa).

V. ANALYSIS RESULT

A static structural analysis calculates the effect of steady (or static) loading conditions and determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Static analysis is done by applying the external and internal load on the specimen. 6 rehabilitated specimens with different stacking sequence of repair laminas were examined for the ultimate strength by dong eigenvalue buckling followed by static analysis. The best rehabilitated specimen is further analysed by changing the thickness of repair laminas.

A. Parameter 1: Stacking Sequence

The varying parameter was the stacking sequence of repair laminas of each 1mm thickness as in Fig. 4. From the buckling analysis result the buckling strength of each specimen obtained is given in Table V.

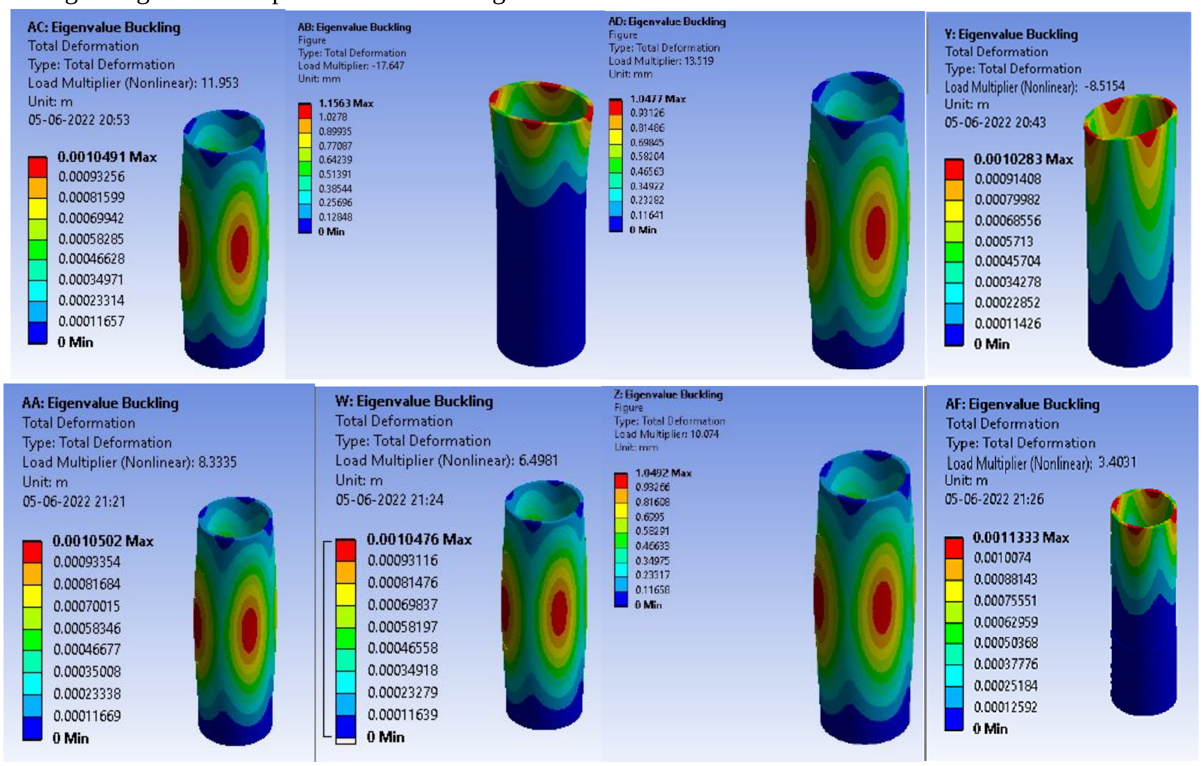

Fig. 4 Analysis Result

TABLE V
ULTIMATE STRENGTH

Specimen Group	Specimen ID	Load Multiplier	Deflection (mm)
Intact	I	8.51	1.0283
Corroded	C	3.40	1.1333
Repaired	GEC	13.51	1.0477
	EGC	11.95	1.0491
	CEG	17.64	1.1563
	GC	8.33	1.050
	EC	10.07	1.0492
	GE	6.47	1.0476

CEG sequence showed better buckling strength result than GEC. But the deformation value of CEG repaired specimen is higher than corroded specimen.

B. Parameter 2: Repair Lamina Thickness

From the first analysis the best sequence having better strength capacity was choosen. The repaired specimen with inner layer GFRP, middle layer ECC and outer layer CFRP having better strength gain was further analysed by changing the repair lamina thickness. From the analysis load-deformation graph was obtained as shown in Fig.5.

(a) 0.5mm Thickness GEC Repair Laminas (b) 0.75mm Thickness GEC Repair Laminas

Fig. 5 Load-Displacement Graph

VI. CONCLUSIONS

Repaired specimens have high buckling strength than corroded specimen which shows the stiffness regaining capacity of repair laminas. The moment of inertia of repaired laminas increased and it resisted the lateral displacement on the corroded area. ECC applied in between FRP layers act as an adhesive agent, which eventually transfer load from one point to another point through fibre bridging. Therefore better stacking sequence obtained was GFRP, ECC, and CFRP. And for getting optimum repairing technique the thickness is reduced to 0.5mm and 0.75mm. Repairing using each layer 0.75mm thickness obtained high ultimate strength and buckling strength close to intact specimen.

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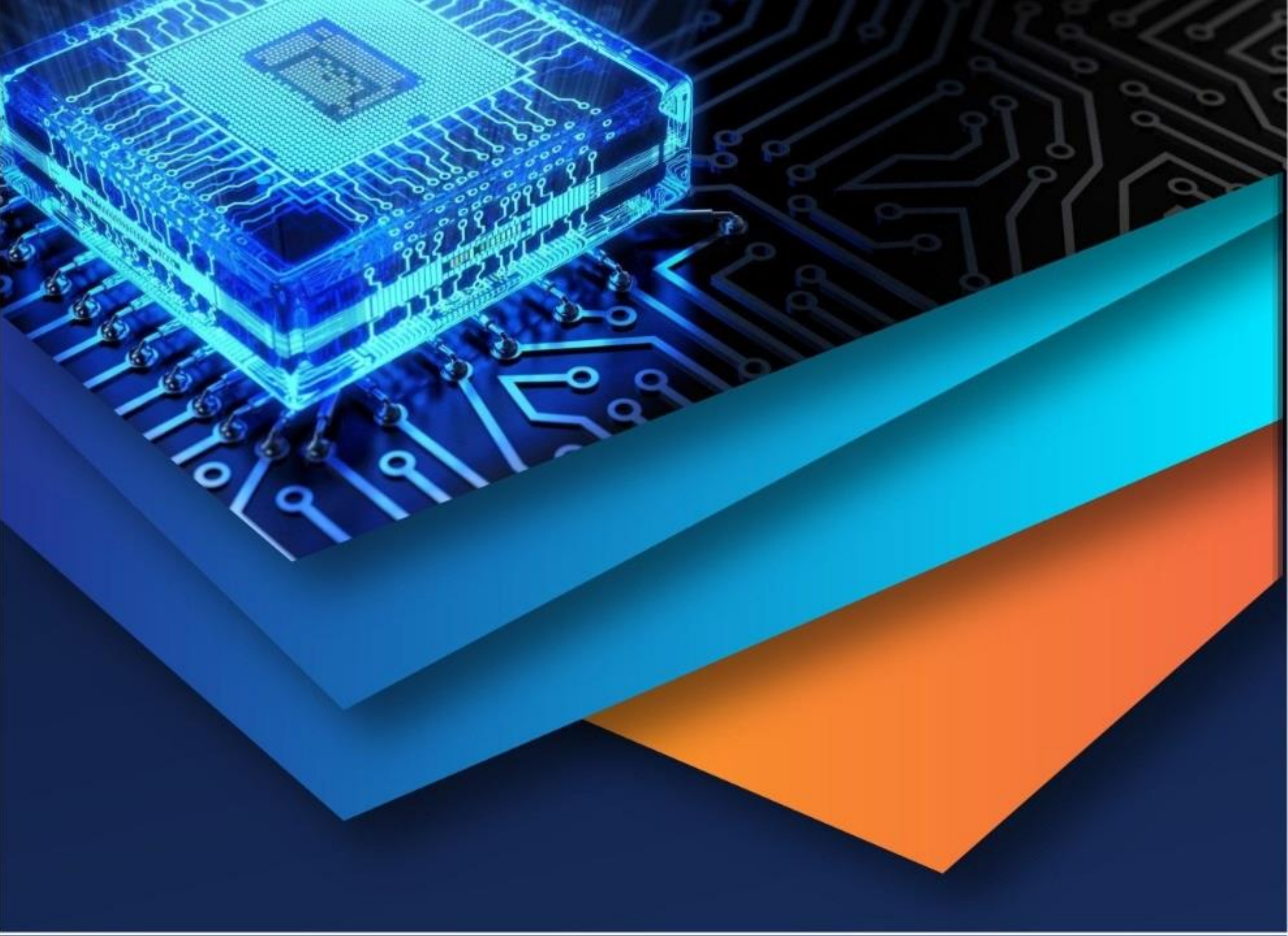

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