THE NULL EFFECT OF CROSS SECTIONS OTHER THAN THE MAXIMUM PITTED CROSS SECTION ON STRENGTH REDUCTION OF AGED MARINE PLATES SUBJECTED TO UNIAXIAL TENSILE LOADING

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ABSTRACT

It is of essential importance to predict the strength reduction due to pitting corrosion for a proper condition assessment of aged ships. The crucial location of maximum pitting as well as the heavy unevenness of the metal surface creates difficulties for the surveyors to perform the survey. Empirical formula based on statistical data can assess the strength reduction due to pitting on the basis of damage intensity where the strength reduction is only a function of maximum pitted cross section. In this study, the formula is established again by nullifying the effect of other cross sections on the strength reduction except the maximum pitted cross section. This null effect of less pitted cross sections will increase the surveyors' confidence to concentrate only on the maximum pitted cross section. A series of finite element analysis is carried out where MSC NASTRAN nonlinear implicit analysis code has been used in large deformation analysis of two different pitted marine steel rectangular plate samples. The pitting patterns of different intensity used in this study were generated by other researchers using a probabilistic corrosion model.

Key words: Strength Reduction, Pitting Corrosion, MSC NASTRAN, Nonlinear Implicit Analysis, Probabilistic Corrosion Mode

1.0 INTRODUCTION

Condition assessment is a very important scheme as many vessels are removed from service before reaching the end of their designed life. A Condition Assessment Program is aimed at determining and assessing the actual technical condition of hull and/or machinery, electrical installation and cargo related systems at a given point of time by surveys and investigations. The purpose of a Condition Assessment Survey is to analyze the remaining strength of the hull structure.

Corrosion wastage is a prominent cause of age related deterioration of steel structures. Metal degrades locally in pit forms reducing strength and deformability, which are main salient features for integrity of steel structures. For a proper condition assessment of aging ships, it is of essential importance to predict the strength and absorbing energy during collapse and/or fracture of corroded plate [1]. According to Nakai et al. [2] it is very important to investigate the effect of corrosion wastage not only on overall strength but also on local strength. They have investigated shape of corrosion pit on a single hull tanker and found circular cone shaped pit on hold frame of bulk carrier and spherical shaped pit on the bottom shell of the tanker. The effect of corrosion is basically the geometric effect and chemistry does not come into play [3]. It is thus of great importance to consider actual shape of pits in study. Paik et al. [4-5] studied the ultimate strength behavior and Sumi [6-7] estimated tensile strength, bending strength and deformability of steel corroded plates considering two types of pit shape. In the present study it is aimed to enhance the periodic survey of Bangladesh marine structure in case of pitted steel plate considering the actual pit shape that observed in Bangladesh marine plate. Strength reduction in a large pitted plate and part of that plate containing maximum pitted cross section is compared by nonlinear finite element analysis. For that material, true stress-true strain relationship is defined from engineering stress strain which is investigated with the help of tensile test by universal testing machine.

2.0 ACTUAL PIT SHAPE OF BANGLADESH MARINE CORRODED PLATE

Munir Hassan investigated the actual pit shape of Bangladesh marine corroded plate in part of his PhD research. He collected a number of pitted plates from different source of Bangladesh inland marine structures and prepared the surfaces by sand blasting. Replication of the surface was done by using fiber glass. Finally he observed the pit cross section as conical (Fig 1). In this study the same pit shape is considered.

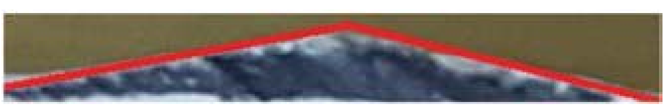


Fig 1. Replication of pitted surface.

The probabilistic corrosion model that was proposed by Yamamoto and Ikegami [8] can quantitatively evaluate generation and progress of corrosion. They estimated parameters governing their probabilistic model for four different locations of ships. M.R. Islam [9] generated data sets by using 'Monte Carlo Simulation' and Three-dimensional computer aided design software 'RHINOCEROS' [10] was used to model the corrosion surface by the NURBS (Non Uniform Rational B-Spline) surfaces.

In the current study the effect of cross sections other than the maximum pitted cross section is nullified by selecting a part of total pitted surface which includes the maximum pitted cross section. Here the length of part is chosen as 20 mm [a random choice] [10mm to each side of the maximum pitted cross section]. So the size of the part is 20 x original breadth of the sample and the location of maximum pitted surface is at middle of the part. The original size of the pitted plate specimen is 200 x 38mm. The location of maximum pitted cross section within the total pitted surface is traced by calculating the average cross sectional material diminution. So the final size of the pitted surface for analysis is 20 x 38mm. The original locations of maximum pitted cross section and cross sections at each side of 10mm is remained same in finite element model (Fig2).

Pit Intensity (DOP: Degree Of pit Intensity)	Total Pitted Surface	Partial Pitted surface containing the maximum pitted cross section at middle
DOP 19		
DOP 51		
DOP 73		
DOP 92		

Fig 2. Simulation images of pitted surfaces.

3.0 MATERIAL DEFINITION

In this study an elastoplastic material is considered. The material definition flow chart is shown in fig 3. True stress strain curve is produced from engineering stress-strain by using the following simple equation.

$\varepsilon_T = \ln(1+\varepsilon_e)$ and $\sigma_T = \sigma_e(1+\varepsilon_e)$

Here, σ_e = engineering stress, ε_e = engineering strain;

σ_T = True stress, ε_T = true strain.

Two types of intact plate, class and local were collected and they were tested by UTM to obtain the engineering stress-strain curve (Fig 4, Fig 5). The chemical composition of the plates was also tested and shown in Table I along with the mechanical properties in Table II.

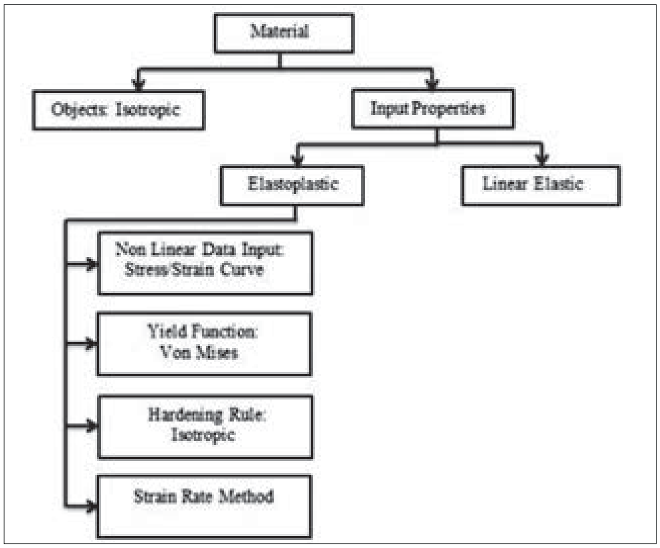


Fig 3. Material definition in MSC Nastran.

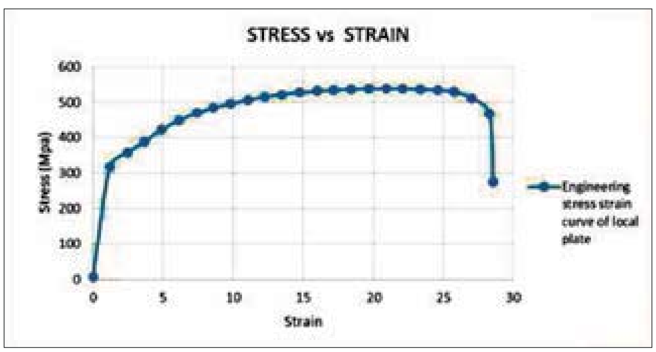


Fig 4. Engineering stress strain curve of local plate.

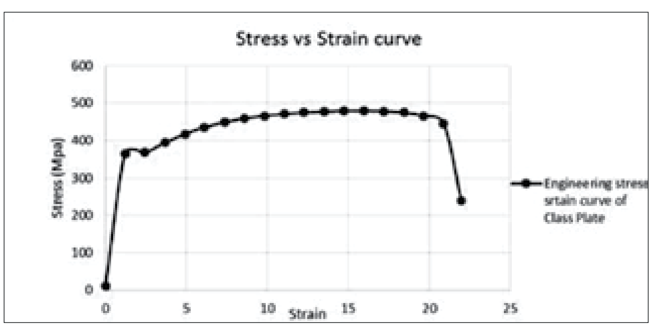


Fig 5. Engineering stress strain curve of class plate.

In case of large and non-uniform deformation the engineering/nominal quantities of stress and strain are valid up to ultimate limit in their true form and can be calculated from engineering part. That is why, the analysis has been done up to the ultimate limit in this study. The engineering stress strain has been converted into true stress strain using equation stated above. These curves were used as material definition.

The true stress strain curve obtained using the formula is shown in fig 6 and fig 7.

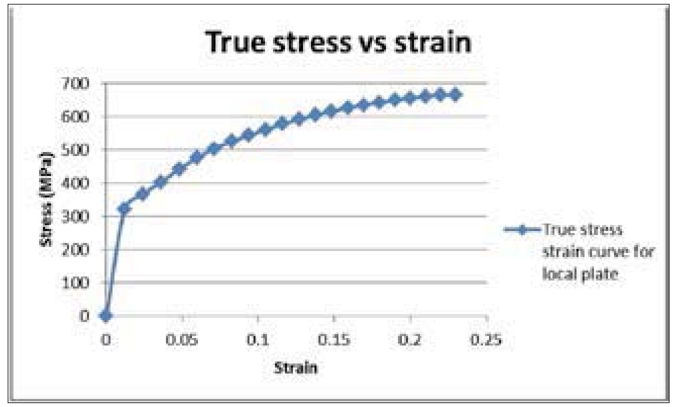


Fig 6. True stress strain curve of local plate.

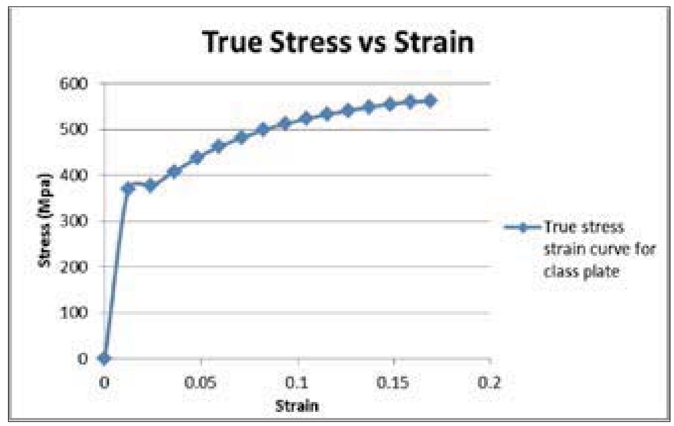


Fig 7. True stress strain curve of class plate

TABLE I. CHEMICAL COMPOSTION

Material	Fe	Mn	P
LOCAL PLATE	98.71	0.606	0.19
CLASS PLATE	99.35	0.426	0.22

TABLE II. MECHANICAL PROPERTIES

Material	Yield Strength (MPa)	Young's Modulus (MPa)	Tensile Strength (MPa)
LOCAL PLATE	316.98	26408.64	537.8
CLASS PLATE	365.54	30180.03	478.98

4.0 FINITE ELEMENT MODEL

The finite element model of test specimen is generated by ‘MSC PATRAN – Academic Version’ [11] using 8-node hexahedron elements (Fig 8(a)). The loading condition is uniaxial and static where all the nodes of one end kept constrained in all directions.

The current model was generated for total pitted surface and total surface but partially pitted which contains maximum pitted cross section. Due to the element number limitation in academic version, the minimum size in loading direction could be

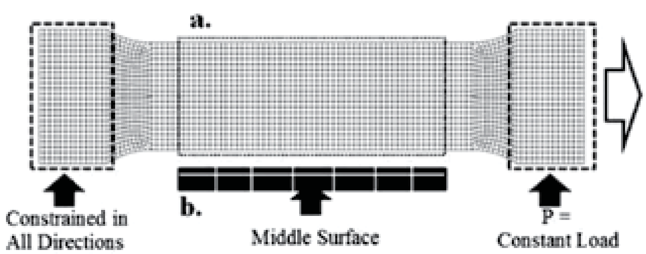


Fig 8. Finite Element Modeling: (a) Boundary Condition; (b) A mid surface is introduced.

The most reasonable element size 1x1x1mm could not be used due to limitation of academic version and DD model was generated having elements of 2x2x2 mm.

5.0 FINITE ELEMENT ANALYSIS RESULT

The validation of input properties was ensured by the FEA of the intact plate (Fig 9) when output curve form the simulation superimposed on the input stress strain curve (Fig 10: Local Plate).

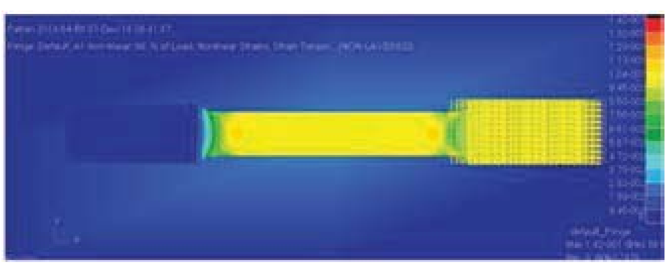


Fig 9. FEA of intact local plate.

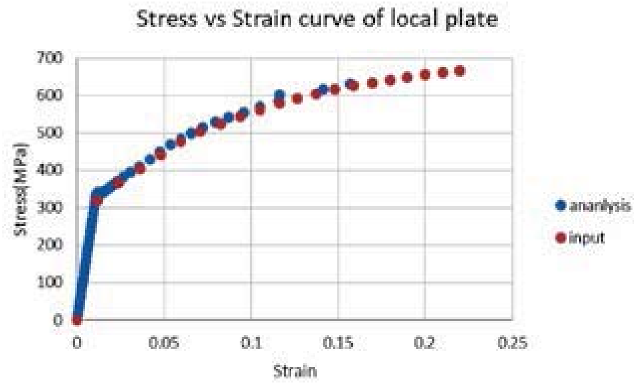


Fig 10. Validation curve of intact local plate properties

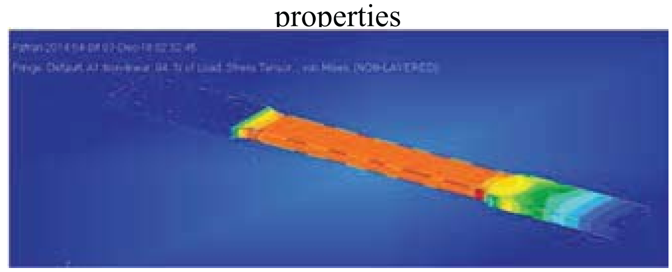


Fig 11. FEA of intact class plate.

In the similar manner the class plates were also simulated and they result in superimposition of input and output curves (fig 12) as it does for local plates.

Later on, non-linear implicit finite element analyses were conducted for both pitted surface and partially pitted surface containing maximum pitted cross sectional area using material definition of class and local plate considering conical pits (fig 13(a), fig 13(b).

Here the superimposition of two curves indicates that total pitted surface and partially pitted surface absorb equal quantity of load to reach to its ultimate limit of stress (fig 13(c).

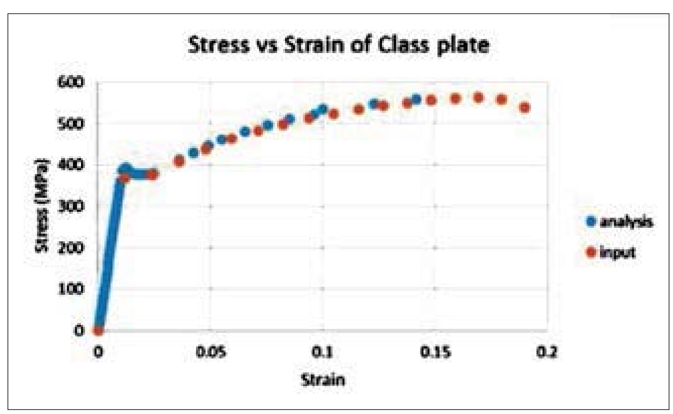
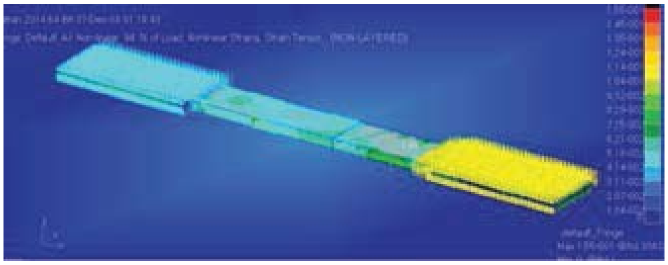
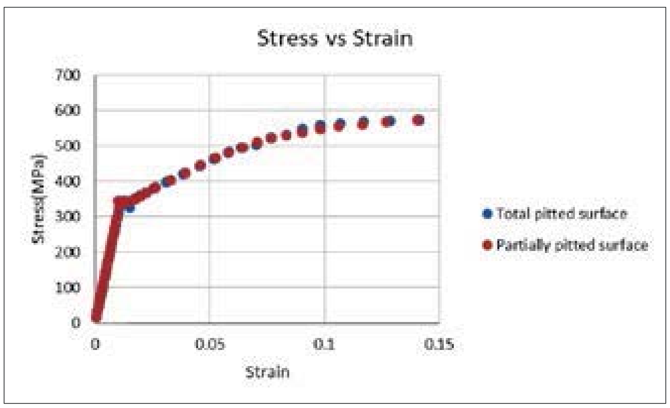


Fig 12. Validation curve of intact class plate properties.

(a)



(b)



(c)

Fig 13. FEA of DOP 19 (a) Total pitted surface, b) Partially pitted surface, (c) output stress strain curve.

The simulations were conducted for both pitted surface and partially pitted surface with maximum pitted cross sectional area using material definition of class and local plate. The ultimate stresses are compiled in TABLE III and TABLE IV.

For both type of plate sizes with increasing number of pit intensity. It can be visible from both the table that, for a particular percentage of pitting occurs in a plate, their stress reached to nearly equal ultimate point irrespective of the plate size. Fig 14 to Fig 20 shows the superimpositions of the input and output curves.

TABLE III. COMPARISON BETWEEN ULTIMATE STRESSES OF PITTED SURFACE AND PARTIALLY PITTED SURFACE

ULTIMATE STRESS in MPa (Local Plate)					
Pit intensity	DOP 0 (intact plate)	DOP 19	DOP 51	DOP 73	DOP 90
Total pitted surface	634.24	580.8	514.9	590.59	478.5
Partially pit-ted surface	634.24	571.3	514.9	485.59	475.8

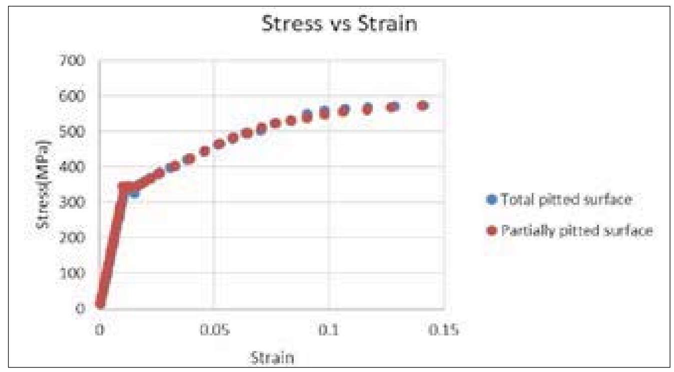


Fig 14. Comparison of total pitted surface and partially pitted surface with DOP 19 of local plate.

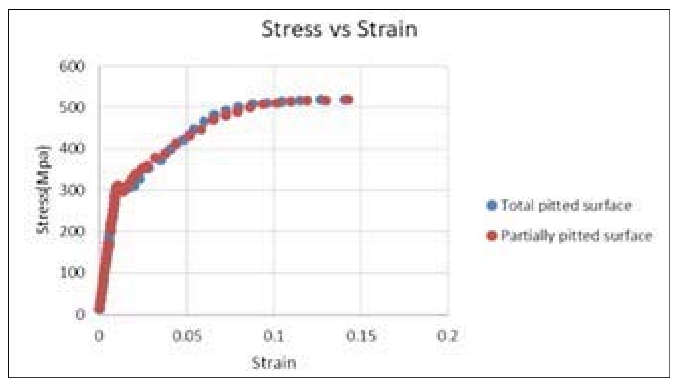


Fig 15. Comparison of total pitted surface and partially pitted surface with DOP 51 of local plate.

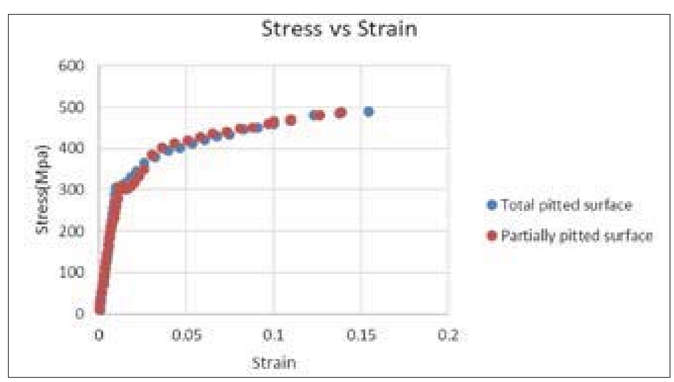


Fig 16. Comparison of total pitted surface and partially pitted surface with DOP 73 for local plate

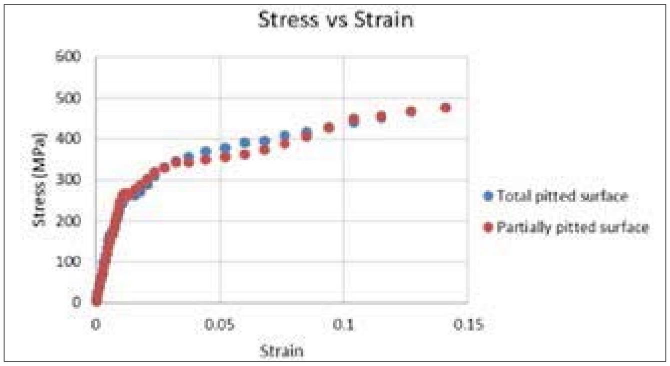


Fig 17. Comparison of total pitted surface and partially pitted surface with DOP 92 for local plate.

TABLE IV. COMPARISON BETWEEN ULTIMATE STRESSES OF PITTED SURFACE AND PARTIALLY PITTED SURFACE.

ULTIMATE STRESS in MPa (Class Plate)					
Pit intensity	DOP 0 (intact plate)	DOP 19	DOP 51	DOP 73	DOP 92
Total pitted surface	599.06	540.90	497.14	492.6	455.32
Partially pitted surface	599.06	541.2	497.14	485.58	452.08

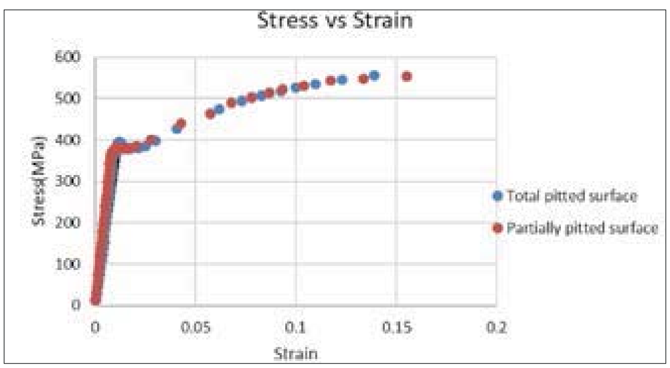


Fig 18. Comparison of total pitted surface and partially pitted surface with DOP 19 for class plate.

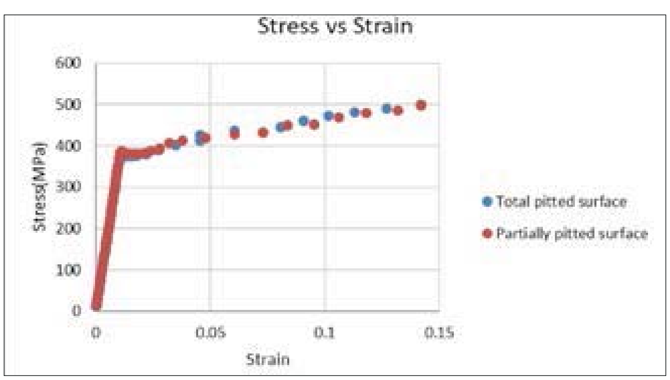


Fig 19. Comparison of full pitted surface and plate.

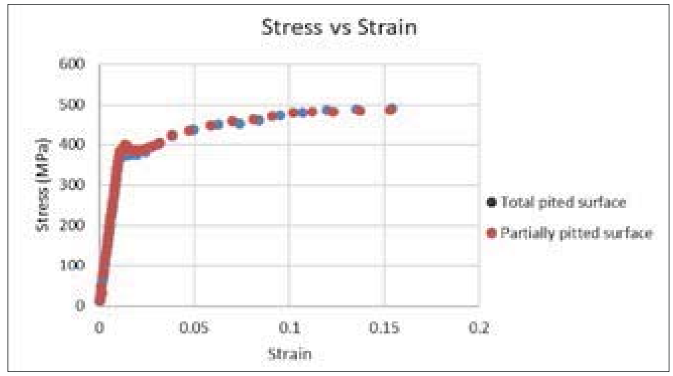


Fig 20. Comparison of total pitted surface and partially pitted surface with DOP 73 for class plate.

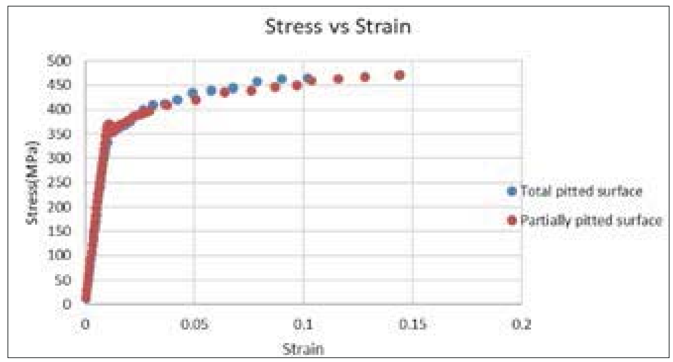


Fig 21. Comparison of total pitted surface and partially pitted surface DOP 92 for class plate.

The finite element analysis results prove that partially pitted surface containing maximum pitted cross sectional area achieves the equal ultimate stress before necking as the total pitted surface does when they are subjected to equal amount of uniaxial tensile loads.

6.0 STRENGTH REDUCTION DUE TO PITTING

The effect of pits on one of the major parameters of structural integrity namely strength reduction been calculated from the simulation results. The stress at ultimate limit has been considered from the strain closest to ultimate strain of the flat plate which was determined from the flat plate simulation at known elongation (from experiment by UTM) of material.

Paik et al. [4] derived an empirical formula for predicting the ultimate compressive strength and shear strength based on minimum cross section of corroded surface considering cylindrical pit shape.

$$Ru=(1-Dm)\ .73 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where Ru is the ultimate strength of pitted plates normalized by that of an intact plate. Which is later on proved by Y Sumi and Ahmmed[6] that the formula is wide applicable in case of conical shape of pits under tensile load.The damage (Dm) is defined by:

$$Dm=(Ao-AP)/Ao \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

Where Ao is the intact sectional area and AP is the smallest cross sectional area due to surface pits. However, in this study reduced strength was calculated from the data obtained from simulation and also using the empirical formula given by Paik et al [4] for both local and class plate taking into consideration of total pitted surface and partially pitted surface containing maximum pitted cross section (Table V, Table VI).

TABLE V. Comparison between R_u of Total Pitted Surface and Partially Pitted Surface (Local Plate)

DOP	A_p	D_m	R_u (numerical data)	Calculation of R_u from FE analysis: Total pitted surface	Total surface but partially pitted
19	63.65	0.16	0.88	.91	0.90
51	53.90	0.29	0.78	0.81	0.81
73	49.27	0.35	0.73	0.77	0.76
92	40.22	0.47	0.63	0.75	0.75

TABLE VI. Comparison between R_u of total pitted surface and partially pitted surface (class plate)

DOP	A_p	D_m	R_u (numerical data)	Calculation of R_u from FE analysis: Total pitted surface	Total surface but partially pitted
19	63.65	0.16	0.88	0.90	0.90
51	53.90	0.29	0.78	0.83	0.83
73	49.27	0.35	0.73	0.82	0.81
92	40.22	0.47	0.63	0.76	0.75

Fig 22 and fig 23 finally shows that strength is reducing in the same pattern for both the pitted surface and partially pitted surface containing maximum pitted cross section. Not only that, they are also nearly equal in magnitude with a variation not more than 6% from the empirical formula.

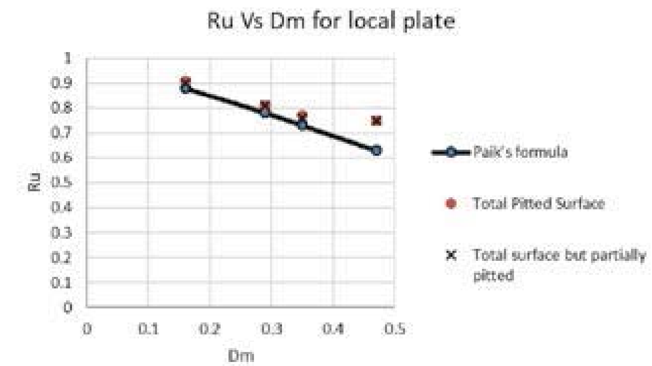


Fig 22. Comparison between strength reduction determined from analysis result and numerical data.

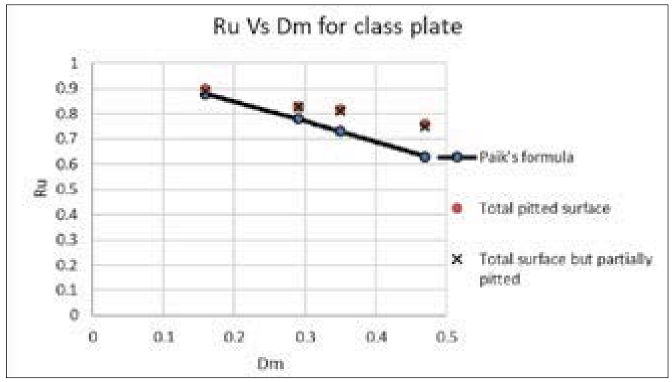


Fig 23. Comparison between strength reduction determined from analysis result and numerical data.

7.0 DISCUSSION

The marine structures are continuously subjected to corrosive environment during their service. It would be helpful if the characteristics of pitting can be predicted earlier through the survey of the vessels and other marine structures for assessing their condition. The study was conducted emphasizing on the effect of maximum pitted ross sectional area on aged marine plate which is subjected to uniaxial tensile loading. From this study, it has been understood that strength reduces and damage increases with increase of degree of pit depth irrespective of their pitting position. The graphical representation shows that Strength reduction factor of total pitted surface and surface containing maximum pitted cross section (partially pitted surface), being analogous in nature and pattern with increase of damage. From this, it can be decided that, only maximum pitted cross section is playing the major role in strength reduction and this proves the nullifying effect of the other cross sections.

8.0 CONCLUSION

During the survey it is essential to examine and inspect the condition of the structures which are subjected to pitting corrosion. This study is focused on the effect of the maximum pitted cross sectional area which is the primary influencing parameter of the strength reduction and the finite element analysis results confirm the null effect of pitted cross sections other than the maximum pitted cross section.

It can be concluded that, concentrating only on that cross section during survey of pitted surface is fair enough to assess the structural integrity of the marine aged structures. This will help the ship owner and the classification society to perform a better planning for the inspection and prediction of the consequent damage of the structure.

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