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Residual compressive strength & probability failure of locally corroded tubular steel columns

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ABSTRACT

The Steel structures can undergo a natural process called corrosion, which can compromise their safety and durability. Given the inevitability of corrosion, it is crucial to evaluate the load-carrying capability of corroded structural components. This study aimed to investigate the impact of localized corrosion on the load-bearing capacity of tubular steel columns subjected to eccentric compression, by conducting parametric finite element analysis and examining the effects of the degree of volume loss (DOV) due to corrosion damage along the column on its residual compressive strength. Additionally, the reliability of corroded steel tubes was evaluated using normal distribution in MATLAB, to estimate the probability of failure and assess the risk of failure.

Keywords - Residual compressive strength, Local corrosion, Global plastic analysis, Degree of corroded volume, probability failure

1. INTRODUCTION

Corrosion is a naturally occurring process in steel that can degrade the performance and durability of structures made of this material. It develops water and moisture are present, oxygen can undergo a chemical reaction (e.g., humidity and vapor). Corrosion decrease the cross-sectional area at certain parts of a steel member rendering the structure vulnerable to failure or requiring costly repairs. To prevent or at least delay the occurrence of corrosion, steel surfaces are usually coated with paint. However, the protective function of paint is not permanent; thus, corrosion develops over time. Based on the preceding information, it can be concluded that corrosion is a natural occurrence in steel materials, making it crucial to evaluate the remaining compressive strength of corroded structures. In the field of construction, tubular columns are typically used in bridges as shown in Fig. 1, as well as offshore and other essential structures. Although tubular columns are advantageous in construction because of their ease in handling and symmetric cross-section, their relatively thin walls render them susceptible to corrosion damage. In earlier studies, practical experimental and numerical analyses were performed on the residual compressive strength of short tubular steel columns with local corrosion. The above suggests that steel materials will inevitably corrode, emphasizing the need to evaluate the remaining compressive strength of structures affected by corrosion and the dimensions of the corrosion was proposed, and a simplified elastic analysis was developed to predict the strength. Based on the above discussion, it becomes clear that steel materials are bound to undergo corrosion, emphasizing the importance of evaluating the remaining compressive strength of structures that have undergone corrosion. This means that the degree of volume loss (DOV) should be considered in the compressive strength of the short columns.

Columns can be classified into three types based on the slenderness ratio: The slenderness ratio refers to the ratio between the effective length and the radius of gyration, and as it increases, the capacity to bear loads decreases.

To account for the Design codes generally offer equations that are best suited for the behavior of columns of varying lengths, taking into account the range of short, intermediate, and long columns and fitting the data accordingly. Previous studies have addressed the compressive strength and behavior of short columns with corrosion, and future studies on the effects of intermediate columns are needed. There is also a need to study the effects of the degree of volume loss (DOV) on the compressive strength of intermediate tubular steel columns with local corrosion effect. In order to predict the performance of columns with varying lengths, design codes typically offer equations that are most suitable for the data falling within the categories of short, intermediate, and long columns with local corrosion effect during eccentric loading. A total of eight column specimens were fabricated as steel columns with corrosion damage of various dimensions (depths, heights, circumferences, and locations). Also, different slenderness columns considered. Based on the results, a simple approach using a proposed method for evaluating the compressive strength of intermediate columns that have undergone local corrosion is to use the degree of volume loss (DOV) as a reduction factor.

. Then last we did probability failure steel column using normal distribution in MATLAB performed to assess its reliability and determine the risk of failure. The result of this study shall help maintenance engineers to solve the problems of steel tube.

Fig 1. Tubular columns in bridges

2. METHODOLOGY

3.1 Validation

From the journal paper of engineering failure analysis 138 (2022) “Residual compressive strength of locally corroded intermediate tubular steel columns”. This study validates with the experimental result from this journal. The specimens used in the test were composed of. Tubular steel columns as below in Fig.2 Based on the results of the study

in the experimental study. The external diameter, wall thickness, and length of each column are 101.6, 5.7, and 2200 mm, respectively. A tensile test conforming to ASTM standard E8/E8M-16 was conducted to confirm the characteristic of material of the fabricated steel columns. The steel grade of the columns was JIS G 3444 STK 540, with a yield strength of over 390 MPa and a tensile strength of over 540 MPa. The yield strength was set at 406 MPa in accordance with the tensile test. To simulate a fixed support 2 at the termination, point of columns, 15-mm thick steel plates with a plane area of 300 mm × 300 mm were welded at both termination point of columns. The model of D2H120C360L50 is taken for validation purpose. The FEA software, ANSYS R2 2022, was employed to perform the numerical analysis of the same intermediate tubular steel columns that were practically tested. The solid 186 element type was used to model the steel tubular columns. This element type was selected to account for large strains in the column. This is because of its reduced integration function, which provides accurate results and reduces the running time of three-dimensional analysis.

The boundary constraints were applied to both ends of the column model. In the upper end, only the degree of freedom to the longitudinal axis has not been restrained to allow the application of the compressive load. In contrast, all 8 the degrees of freedom in the lower end have been constrained. It was challenging to accurately measure the actual geometric imperfection due to its small value. Therefore, the FEA models used the calculated geometric imperfection from Eurocode 3. Buckling curve, a, which corresponds to a hollow cross-section with yield stress less than 460 MPa, was adopted for this study. The calculated geometric imperfection value for the column specimens was 7 mm; this value was also used in the numerical models.

By analysis of D2H120C360 get the result of residual strength of steel tube is 380.06 Mpa while the experimental result is 400 Mpa that are shown below in table. also, we can see the vertical displacement vs load of both cases. The percentage error of validate result with experimental result are 5.25%.

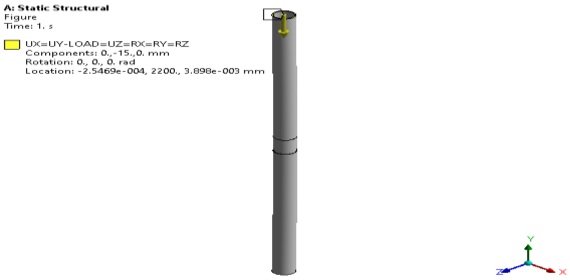


Fig 2. Geometry of D2H120C360L50

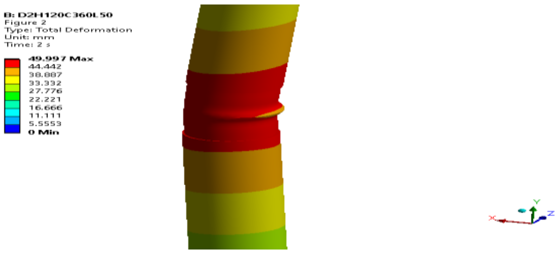


Fig.3 Total deformation validate result

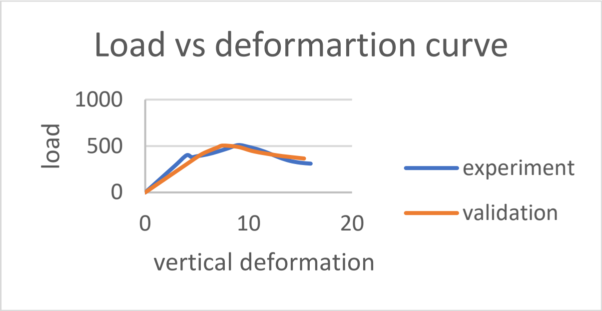


Fig 4. load vs deformation curve of validation

Table 1. validated result

	Yield load (kN)
Experimental	400
FEA	380.06
% of error	5.25

2.2 Numerical analysis of the study

The FEA software, ANSYS R2 2022, was employed to perform for the numerical analysis of eight tubular steel columns, the same material properties as those obtained from validation using tensile tests were utilized in finite element models. Solid186 element type was utilized in eight models for numerical analysis. The finite element software used reduced integration model elements to account for large strains on the specimen. This approach typically provides more precise outcomes and reduces computation time, particularly for three-dimensional analyses. Each model has given eccentric loading at 5 different positions from center of steel tube (E10%, E20%, E30%, E40%, E50%). For example, load act at 5.04mm means load act at distance from center of 10% of radius of steel tube.

The ends of the columns were subjected to boundary conditions. Both terminate point were constrained for all degrees of freedom, except for z-axis rotation. Loading was applied using a displacement controlled method to evaluate the post-buckling behavior of the column. The total compression was divided into several steps, and the shape and axial shortening of the specimen were calculated for each step based on the previous steps.. Regular meshing was used for non-corroded specimens, while irregular meshing was used for corroded specimens, as shown in Fig5. A nonlinear analysis was performed using the Static Risk Analysis step in the software, which generated load capacity versus vertical displacement curves. The load at yield was considered as the remaining compressive strength of the columns as the yield stress is associated with the allowable stress of a tubular column according to the AISI standards.

The corrosion effect is fabricated with different depths (0, 2, and 4 mm), heights (0, 20, 60, and 120 mm), circumferences (0◦, 180◦, and 360◦). These corrosion damage dimensions of the models are listed in Table 2. The notations D, H, C, and L indicate the corrosion damaged depth, height, circumference, and location of corrosion damage along the column, respectively. But here location not considered because of previous study concluded that location change not affect the strength. Therefore, D2H20C360L50 is a column with 1 corrosion depth, height, and circumference of 2 mm, 20 mm, and 360◦, respectively, and the corrosion damage is located at 50% of the column length or at the middle of the column.

Table 2 Test Specimen

Corrosion Hight (mm)	Corrosion depth (mm)	Circum (degree)	model
0	0	360	DOH0C0L0
20	2	360	D2H20C360L50
60	2	360	D2H60C360L50
60	4	360	D4H60C360L50
120	2	180	D2H120C180L50
	2	360	D2H120C360L50
	2	360	D2H120C360L50 short
	2	360	D2H120C360L50 stub

Due to the small value, it was challenging to measure the actual geometric imperfection accurately. Therefore, the FEA models used the calculated geometric imperfection from Eurocode 3. The choice of buckling curve a was made for this study because it corresponds to a hollow cross-section with a yield stress (σy) lower than 460 MPa. The calculated geometric imperfection value for the intermediate column specimens was 7 mm; this value was also 1 used in the finite numerical models.

Fig 5. meshing of model & boundary condition

2.3 Probability failure of steel tube

To estimate the probability of failure of a corroded steel tube by normal distribution using MATLAB, assuming the yield strength is available, you can follow the following steps:

Define the problem: Define the specific problem and the parameters that need to be analyzed. This could include the type of steel tube, its intended use, the conditions under which it will be used, the degree of corrosion, and the yield strength of the tube.

Determine the stress on the corroded steel tube: Determine the stress on the corroded steel tube using the given operating conditions and the geometry of the tube. The stress can be calculated using stress analysis techniques, such as finite element analysis.

Calculate the critical strength using Euler's formula which also performed in MATLAB Software which calculate critical strength on the steel tube

calculate the likelihood of the tube failing by using the normal distribution. To achieve this, you can utilize the cumulative distribution function (CDF) of the normal distribution. This function requires the mean and standard deviation as input. Based on critical strength we can find out the probability failure using MATLAB USING Suitable code.

Use MATLAB to simulate the normal distribution: Use the MATLAB programming language to simulate the normal distribution and estimate the probability of failure for the corroded steel tube. MATLAB has many built-in functions and tools that can be used for this purpose, Toolbox for Statistics and Machine Learning.

```
>> % Step 1: Import the data
data = [ 278, 244.52, 221.2, 202.79, 197.46];

% Step 2: Calculate the mean and standard deviation
mu = mean(data);
sigma = std(data);

% Step 3: Fit the normal distribution
x = 50:300;
y = normpdf(x,mu,sigma);

% Step 4: Calculate the probability of failure
critical_value   165.8475
prob_failure = 1 - normcdf(critical_value,mu,sigma);

% Step 5: Plot the results
figure;
plot(x,y);
xlabel('Residual Stress (MPa)')
ylabel('Probability of failure')
title('Probability of Failure for D0H0C0L0')
hold on;
line([critical_value critical_value],[0 max(y)],'Color','red');

% Step 6: Generate a PDF report
print -dpdf report.pdf

critical_value =

  165.8475
```

Name	Value
A	8.8416e-04
critical_value	165.8475
d	0.0959
D	0.1016
data	[278,244.5200,22...
E	2.0000e+11
I	1.0786e-06
K	1
L	2.2000
mu	228.7920
nu	0.3000
prob_failure	[illegible]
sigma	35.6770
sigma_crit	[illegible]
x	1x251 double
y	1x251 double

Fig .6. MATLAB programming for probability failurr

3. RESILT & DISCUSSION

3.1 Finite element analysis result

The load capacity versus vertical displacement curves were plotted using the results of the finite element analysis. The yield load was obtained from these curves, and if it was not clearly identifiable, the Copland's yield point method was employed.

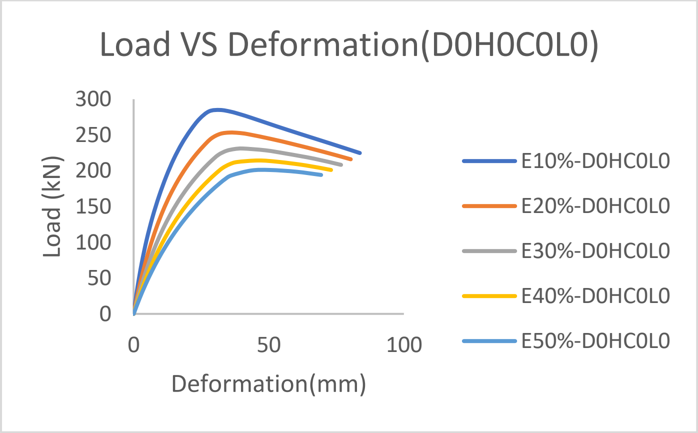


Fig 7 load vs deformation (D0H0C0L0)

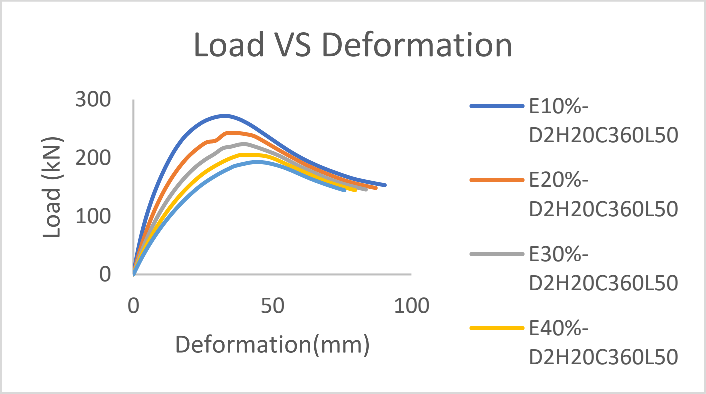


Fig 8. load vs deformation (D2H20C360L50)

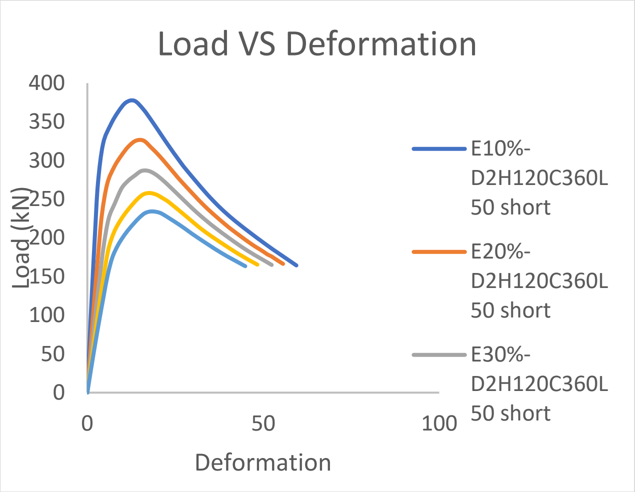


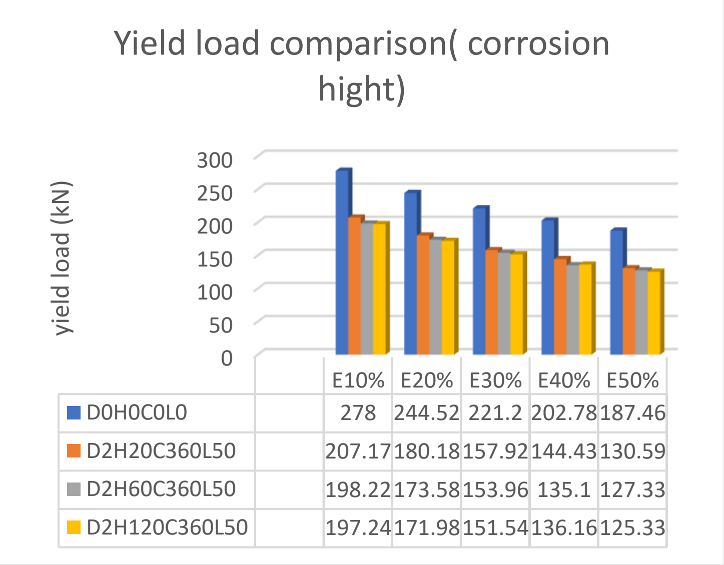
Fig 9 load vs deformation (D2H120C360L50 short)

Table 3 % loss of Py & Pu by eccentricity

Model	% loss of Py	% loss of Pu
DOH0C0L0	14 to 48	12 to 42
D2H20C360L50	15 to 59	11 to 41
D2H60C360L50	14 to 59	11 to 39
D4H60C360L50	16 to 58	12 to 43
D2H120C360L50	15 to 58	11 to 37
D2H120C180L50	15 to 58	11 to 33
D2H120C360L50 SHORT	15 to 59	24 % to 82%
D2H120C360L50 STUB	15 % 59 %	11 to 41

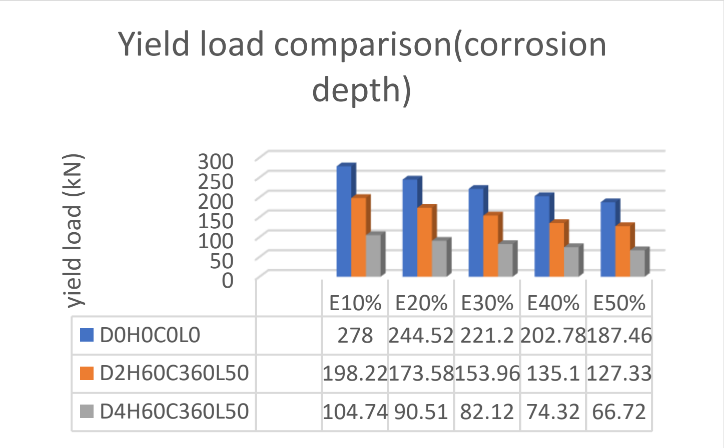
From table 3 we can see yield strength of all steel tube model have decrease the when eccentricity distance 10 % to 50%. For non-corroded steel tube, the loss of yield is 14 % to 48% and ultimate load loss is 12% to 42%when eccentricity increasing. For D2H120C180L50 loss of Py is 15% to 58% and loss of Pu is 11% t0 33%. For D2H20C360L50 loss of Py is 15% to 59% and loss of Pu is 11% to 41%.%. For D2H60C360L50 loss of Py is 14% to 59% and loss of Pu is 11% to 39%.%. For D4H60C360L50 loss of Py is 16% to 58% and loss of Pu is 12% to 43%.%. For D2H120C360L50 loss of Py is 15% to 58% and loss of Pu is 11% to 37%.%. For D2H120C360L50 short column loss of Py is 15% to 59% and loss of Pu is 24% to 82%.%. For D12H20C360L50 stub column loss of Py is 15% to 59% and loss of Pu is 11% to 41%.

The yield as residual strength of steel tube is decreases with corrosion depth increases. when hight 0 to 20 mm the strength will decrease largely but after increasing hight only slight decreases in strength. when corrosion depth increases the large amount of loss in residual strength (0, 2, 4 mm). When corrosion circumference increases the amount of loss of yield load is decreases when (0,180,360 degree). also when slenderness ratio decreases the residual strength will increases.



	E10%	E20%	E30%	E40%	E50%
D0H0C0L0	278	244.52	221.2	202.78	187.46
D2H20C360L50	207.17	180.18	157.92	144.43	130.59
D2H60C360L50	198.22	173.58	153.96	135.1	127.33
D2H120C360L50	197.24	171.98	151.54	136.16	125.33

Fig.10. Yield load comparison (corrosion hight)



	E10%	E20%	E30%	E40%	E50%
D0H0C0L0	278	244.52	221.2	202.78	187.46
D2H60C360L50	198.22	173.58	153.96	135.1	127.33
D4H60C360L50	104.74	90.51	82.12	74.32	66.72

Fig .11 Yield load comparison (corrosion depth)

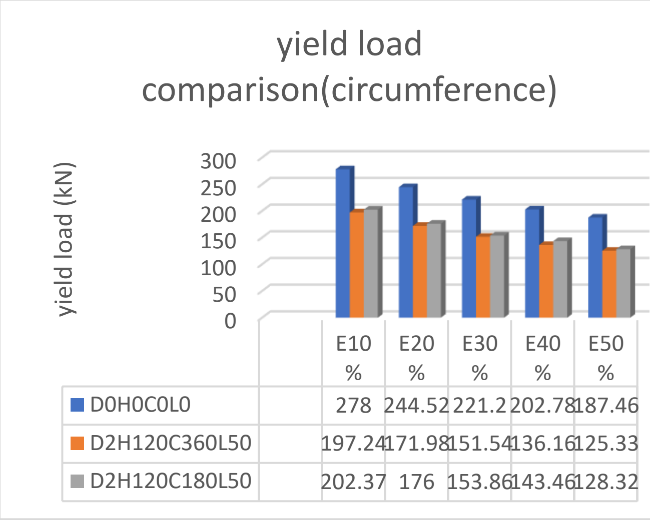


Fig .12. yield load comparison(circumference)

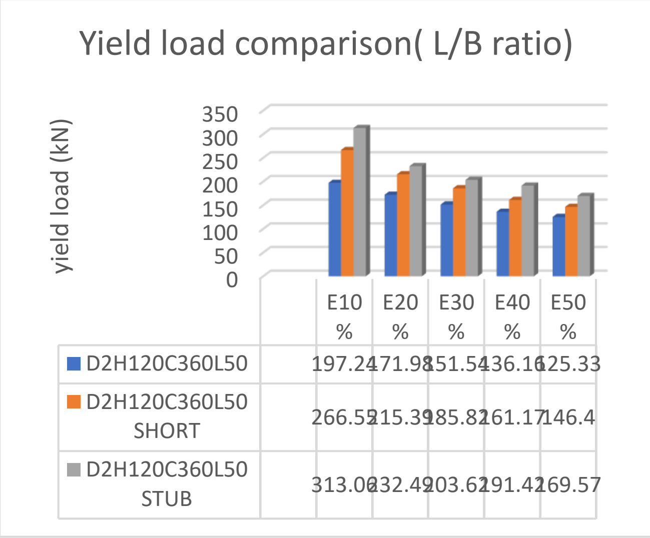


Fig 13. Yield load comparison(L/B ratio)

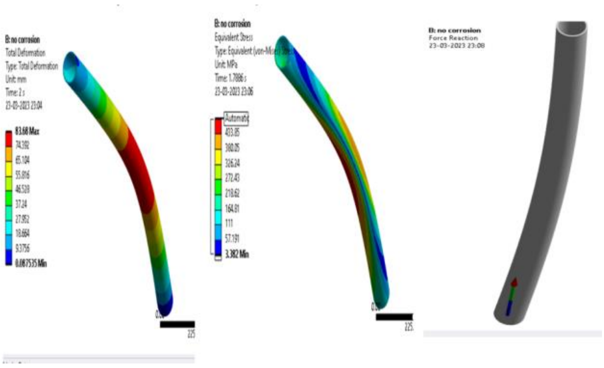


Fig .14. total deformation,stress& force reaction of non corroded steel tube

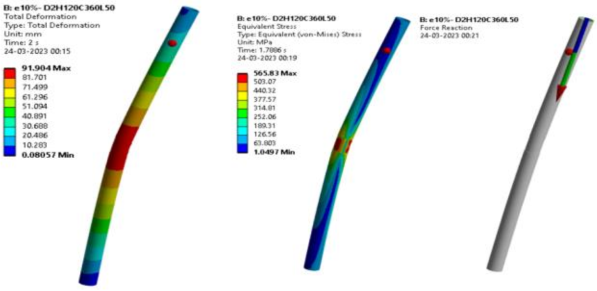


Fig .15. total deformation,stress& force reaction of model D2H120C360L50

3.2 Probability failure of corroded steel tube

Probability failure of each model is determined by using MATLAB using normal distribution.based on critical strength of steel tube he probabilty failure curve is plotted as horizontal as residual stress and vertical as probability failure for difrrent steel tube.for non corroded steel tube the probabilty failure is 0.22% .for 20mm,60mm 120mm corrsion hight there is almost same probabilty failure.also in case circumfernce there is no changes when considering critical strength of steel tube.

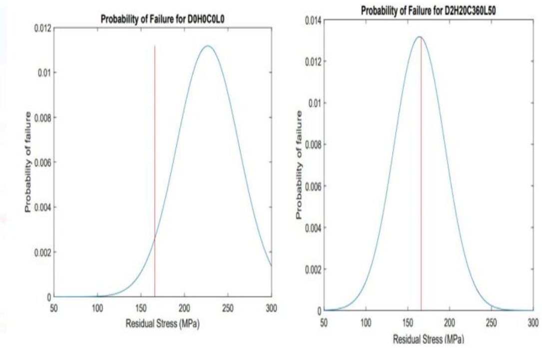


Fig .16 probabilty failure of D0H0C0L0& D2H20C360L50

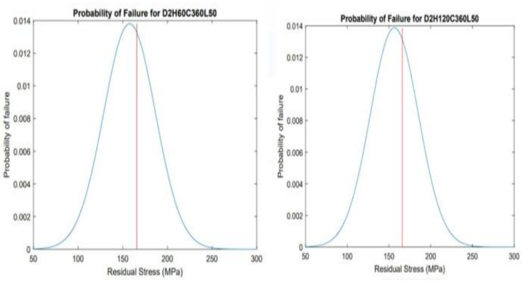


Fig 17.probability failure of D2H60C360L50&D2H120C360L50

Table 4. probabilty failure of models

MODEL	Probability failure %
D0H0C0L0	0.22
D2H20C360L50	1.3
D2H60H360L50	1.25
D2H120C360L50	1.2

5. CONCLUSION

- In this study to investigate the strength variation when eccentric load acting on corroded steel tube. when eccentricity increases yield strength and ultimate load also increases.
- Investigate the changes in the compressive strengths of columns damaged by local corrosion. The local corrosion damage had varied depths, heights, & circumferences along the columns and also probability failure of teel tube is found.
- ➢ When corrosion hight increases residual strength reduces slightly.
- ➢ When corrosion depth increases residual strength reduces very largely.
- ➢ When corrosion circumference increases there is slight variation in residual strength.
- ➢ yield load of short column is large compared to normal column, Yield load of stub column more than compared to short column.
- Probability failure of corroded steel tube based on critical strength there is only slight changes on different steel tubes.

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