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CORROSIVE IMPACTS OF THE MARINE SPLASH ZONE ON STEEL IN MARINE CONSTRUCTION

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ABSTRACT

Hazard and risk assessment for structures suffering from corrosion losses is a subject that demands precision in order to mitigate safety concerns. Therefore, engineers ought to develop practical methods of assessing the severity of corrosive damage. This paper analyzed marine corrosion of steel in the marine splash zone (MSZ) as defined in [1], and developed a model in Visual Analysis simulating the effects of corrosion on a pier structure. Gradual corrosion in the experimental model was reflected in supporting columns by uniform diameter losses in sections along the lengths to simulate the corrosive environment of the MSZ. Loss of residual strength was estimated using output values of extreme absolute stress in the MSZ. Results, as expected, coincided with other research correlating corrosion and decreases in both residual strength and service life. However, the experiment emphasized the structural significance of the MSZ in relation to marine corrosion and contributions to failure conditions. Additionally, the results of this study may be used to coordinate timely servicing or replacement of structures suffering from excessive corrosive damage

INTRODUCTION

Environmental exposure has potential to cause damage if neglected. For steel, the most damaging of these effects is corrosion, which chemically denatures steel [2], causing a decrease in the material's residual strength. Unmonitored corrosive effects have the potential to undermine the integrity of a successful structure design through disastrous failures, as observed in the complete collapse of the I-35W bridge [3]. Furthermore, structural corrosion in the United States alone has been projected to cost an estimated $300 billion annually [4]. Therefore, reliable estimates of residual strength play a critical role in mitigating the disastrous effects of excessive corrosion. Marine environments are among the most corrosive natural environments for steel [5], especially within the marine splash zone, or MSZ [1]. Therefore, the design of steel structures in marine environments should consider corrosion within the MSZ. This experiment follows the observation of the MSZ based on [1], which observed the spike in corrosion along the MSZ, the region immediately above the mean high water level (MHWL), as represented in **Fig. 2**. The range estimates derived in the study were adopted to recreate corrosive effects as observed in [1]. This experiment aims to analyze the significance of the MSZ and the MSZ'CP as they relate to corrosion on marine structures.

METHODS

The procedure for this experiment involves analyzing the corrosion effects over the course of an observational period beginning with no corrosion and ending with failure.

1. First, the control model was rendered using Visual Analysis (VA) [6], a structural engineering software, according to the design procedure elaborated in the paper.
2. Following the construction of the pier, both dead and live gravity loads and wave loads were placed to simulate expected structural demand. Customized factored load combinations of the loads were produced in order to satisfy design checks.
3. After rendering the control model, experimental model copies were created by iterations along the observation period from control (T-0) to failure.
4. Then, the diameter of the individual sections along the MSZ were reduced according to experimental data from [1] sequentially in experimental iterations.
5. The procedure was then repeated using columns of varying initial outside diameter with the same thickness (D14 and D18) in order to observe contrasts in data trends.
6. Next, the column stress data was derived from the member report for all iterations of D14-D18, compiled into **Table 1**, and plotted graphically in **Fig. 4.**

RESULTS ANALYSIS

Fig. 1 indicates a structural error along C2 within the 60th-year iteration (T-6) suggesting failure at that point, consistent between models D14-D18. Therefore, T-6 is defined as the average failure point, by measure of corrosive exposure in decades. **Table 1** represents the increase in C2 absolute max stress and increase in % loss of available area with respect to time in years of models D14-D18, later plotted in **Fig. 3**. The data from **Fig. 3** represents the consequential effect that percent decreases of the available cross-sectional area have on the maximum stress on the C2 section of the pier columns. Based on observations of the data represented in **Fig. 3**, the lines for D14-D18 appear to be nearly linear until about the 75% area loss point. At this point, further area losses result in a spike in the resultant absolute stress on C2 due to the acceleration of the increase in the ratio of area lost compared to available area. The results follow the expected trends between stress and area. However, based on the accelerated corrosion rate in C2, the area losses are dramatically greater than in the rest of the MSZ. Therefore, excess corrosive damage will cause failure exclusively along section C2. The effects of failure along C2 would deliver total failure across the pier due to lack of vertical support. The three curves generated from the stress data of D14-D18 (**Fig. 3**) all have the same general curvature, suggesting similar corrosion patterns and stress increases proportional to exposure time. Furthermore, the data implies that while there are observable differences in resultant stress due to changes in area, the thickness of the steel shapes has much more influence on the expected service life of a structure.

Fig. 1 Displays the design view of the pier structure in VA, with a design error suggesting failure along C2 at T-6 (D16)

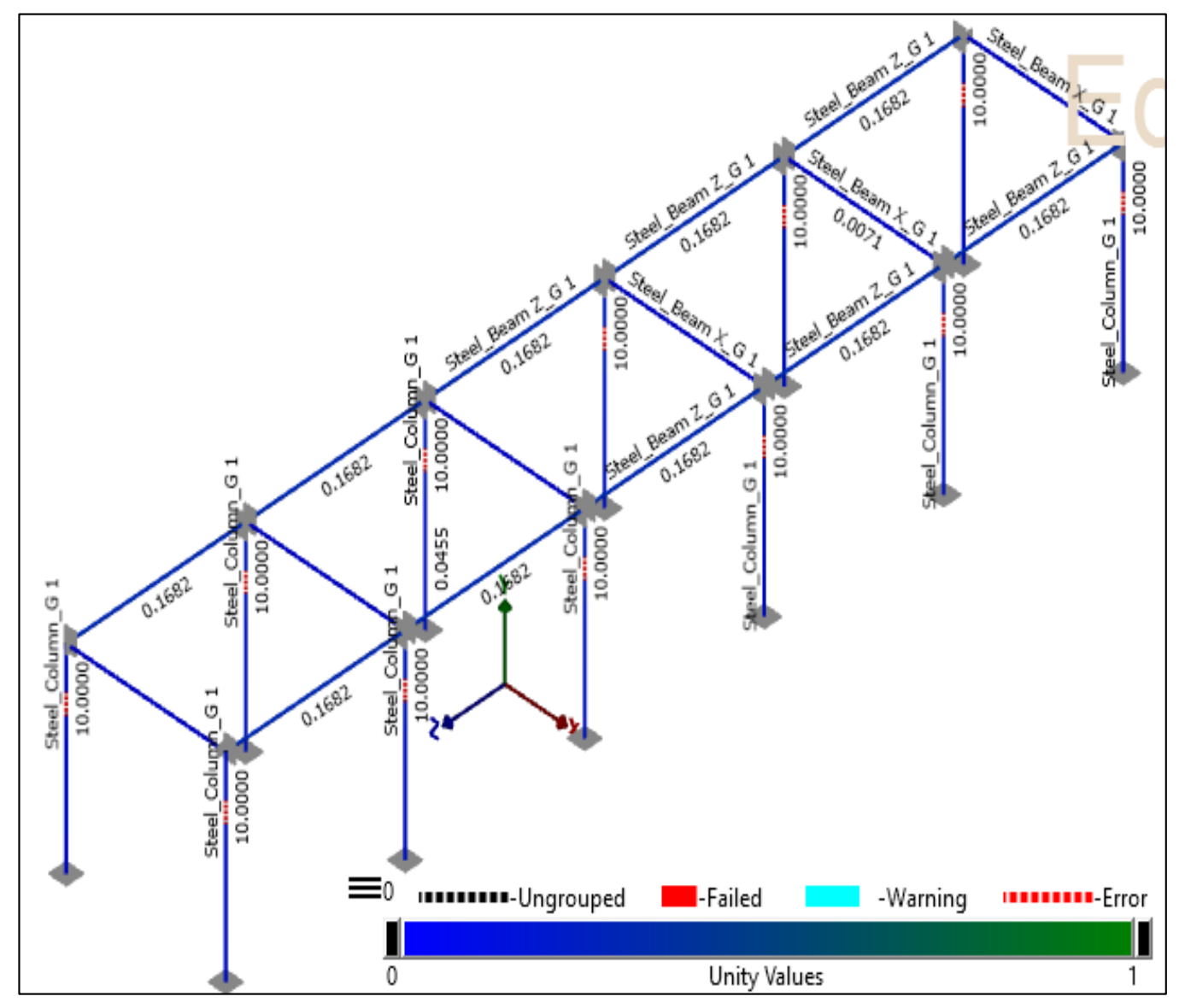
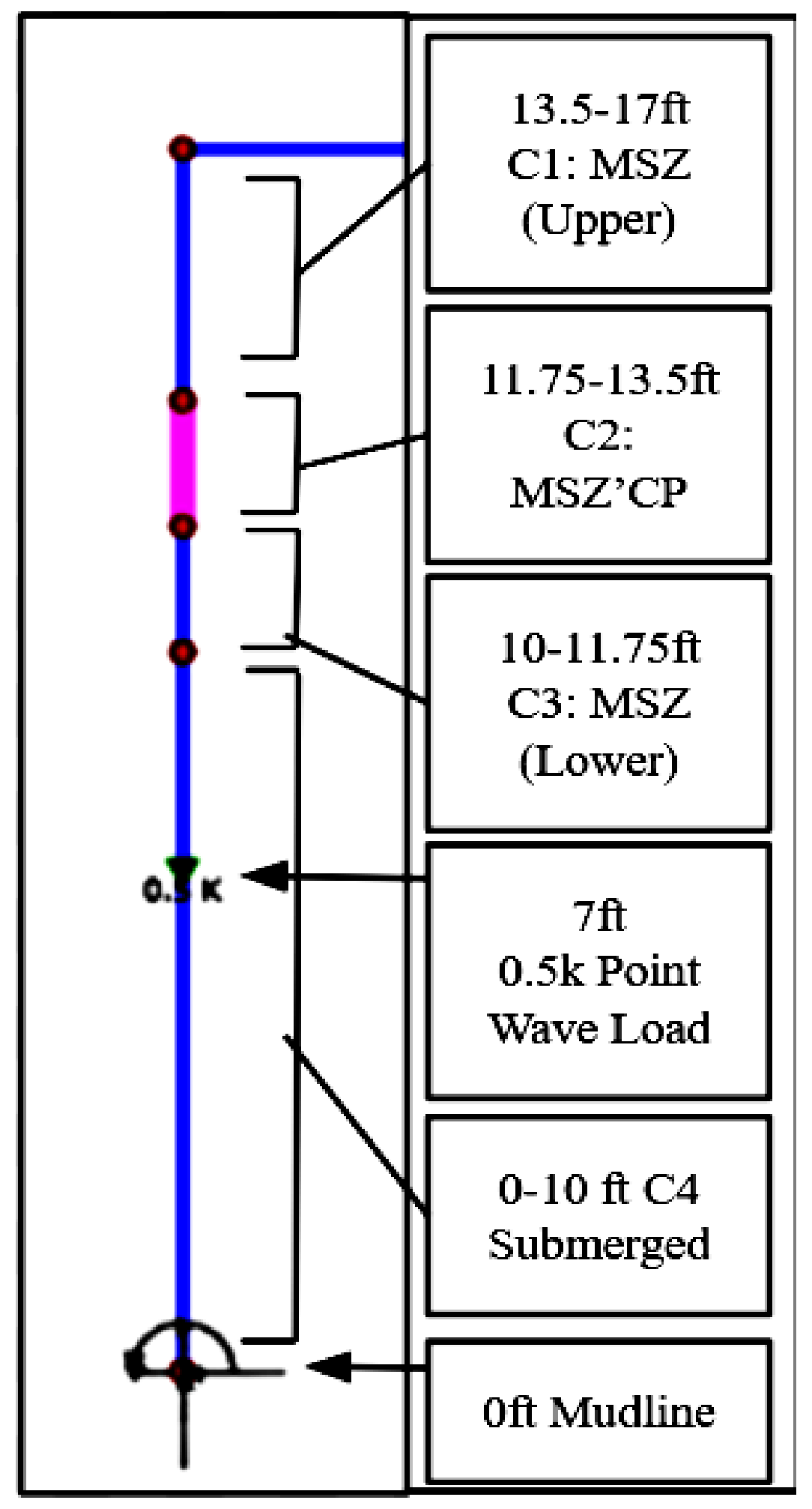


Table 1 Displays the data associated with iterations of the experimental model of time, % area loss, and max stress in section C2

		D14		D16		D18	
Name	Year	% Area Loss	C2 Max Stress	% Area Loss	C2 Max Stress	% Area Loss	C2 Max Stress
T-0	0	0	2.4032	0	2.0689	0	1.8167
T-1	10	16.239	2.8635	16.176	2.4645	16.127	2.1633
T-2	20	32.295	3.5345	32.192	3.0413	32.113	2.6689
T-3	30	48.167	4.6036	48.048	3.9611	47.956	3.4754
T-4	40	63.856	6.5765	63.744	5.6599	63.658	4.9661
T-4a	45	71.631	8.3568	71.532	7.1944	71.456	6.3134
T-5	50	79.360	11.4448	79.280	9.8585	79.218	8.6542
T-5a	55	87.044	18.1272	86.988	15.6316	86.945	13.7321
T-6	60	94.681	43.6038	94.656	37.6929	94.637	33.1729


13.5-17ft
C1: MSZ
(Upper)

11.75-13.5ft
C2:
MSZ'CP

10-11.75ft
C3: MSZ
(Lower)

7ft
0.5k Point
Wave Load

0-10 ft C4
Submerged

0ft Mudline

Fig. 2 Displays the elevation a supporting column, with each section of the column labeled with respect to its location along the MSZ

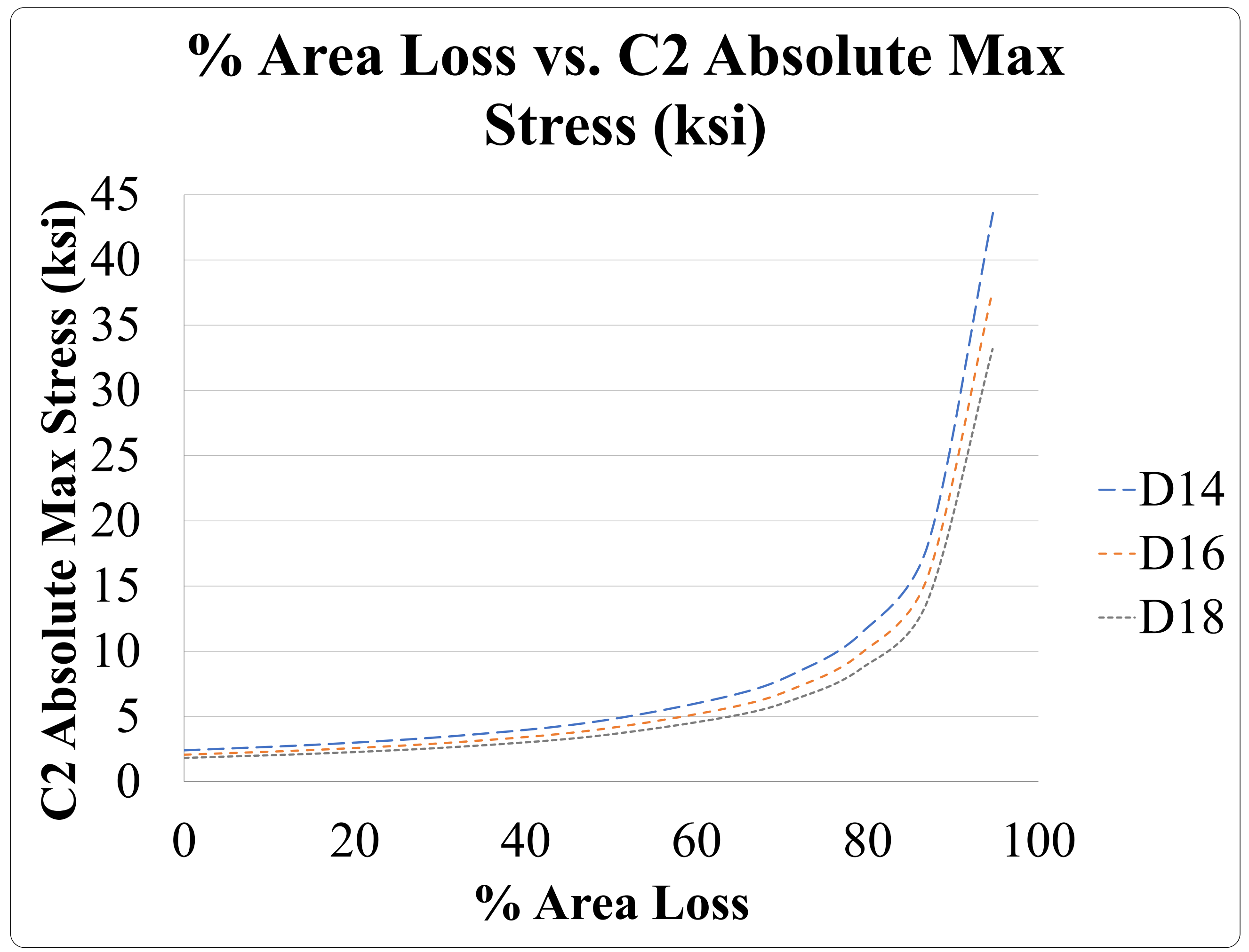


*Fig. 3 Plots the data from **Table 1** to compare how models D14-D18 behave in response to corrosive losses*

DISCUSSION

To focus the study to the subject discussed, several limitations were considered, which must be properly addressed to assess the accuracy of results. Firstly, the assumption of a static corrosion rate is generously ideal, but is employed as a means of analyzing fundamental corrosion principles of gradual material loss. Then, the MSZ and, by extension, the MSZ'CP vary based on local marine and meteorological conditions [1]. This study assumes both conditions remain static during the observational window, which contrasts real conditions. Additionally, corrosive activity along steel surfaces is too dynamic to be considered nearly uniform [7] along the length of sectioned members. Instead, real corrosion will produce deformities, namely pitting, along steel surfaces. The presence of these deformities will gradually cause the development of different structural effects than uniform corrosion alone [8]. Many steel structures will incorporate a protection mechanism to mitigate or reduce the effects of corrosion. However, no protection is used at any point in the experiment. Even with the modeling limitations encountered, the experiment provided insights toward corrosive qualities of partially-submerged structures. Though the results collected in the experiment accurately correlate to general trends, they also stress the structural significance of the MSZ and MSZ'CP despite experimental limitations. While further investigating the structural significance of the MSZ, a similar experiment should be conducted using more realistic corrosion geometry and sectional corrosive variations.

CONCLUSIONS

The stress data relative to area loss is representative of fundamental relationships between area and stress, as expected. Despite the similarity between expected trends and the resultant data, the trends in stress values associated with the MSZ'CP suggest its structural significance. Correlations between stress and percent area loss show that after an area reduction of about 75%, there is a spike in absolute stress, which preludes the approach of failure conditions along section C2 (MSZ'CP). The comparison of stress trends between D14-D18 communicates that larger areas suffer relatively lower rates of stress increases with proportion to percent area losses, while not significant provided the collective failure at T-6 for D14-D18. Furthermore, based on the projection of corrosion rates, it is clear that the thickness of a member is the geometric factor which most influentially determines limiting the life span of a structure exposed to corrosive effects. Given that structural failure along nearly any section of the supporting columns could translate to total failure, the results of the experiment suggest that the accelerated corrosion rates characteristic of the MSZ and MSZ'CP demand special attention when dealing with partially-submerged structures in marine structures.

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