



REMEDIAL ACTION FOR FAILED POLE/BASE PLATE WELD ON HIGH MAST  
LIGHTING POLE (HMLP)

FDOT Contract Number: BD-015-023

Final Report

Submitted to  
The Florida Department of Transportation  
Research Center  
605 Suwannee Street, MS 30  
Tallahassee, FL 32399

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December 2009

## **Disclaimer**

“The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.”

## APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
<b>LENGTH</b>				
<b>in</b>	inches	25.4	millimeters	mm
<b>ft</b>	feet	0.305	meters	m
<b>yd</b>	yards	0.914	meters	m
<b>mi</b>	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
<b>AREA</b>				
<b>in<sup>2</sup></b>	squareinches	645.2	square millimeters	mm <sup>2</sup>
<b>ft<sup>2</sup></b>	squarefeet	0.093	square meters	m <sup>2</sup>
<b>yd<sup>2</sup></b>	square yard	0.836	square meters	m <sup>2</sup>
<b>ac</b>	acres	0.405	hectares	ha
<b>mi<sup>2</sup></b>	square miles	2.59	square kilometers	km <sup>2</sup>

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
<b>VOLUME</b>				
<b>fl oz</b>	fluid ounces	29.57	milliliters	mL
<b>gal</b>	gallons	3.785	liters	L
<b>ft<sup>3</sup></b>	cubic feet	0.028	cubic meters	m <sup>3</sup>
<b>yd<sup>3</sup></b>	cubic yards	0.765	cubic meters	m <sup>3</sup>
NOTE: volumes greater than 1000 L shall be shown in m <sup>3</sup>				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
<b>MASS</b>				
<b>oz</b>	ounces	28.35	grams	g
<b>lb</b>	pounds	0.454	kilograms	kg
<b>T</b>	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

<b>SYMBOL</b>	<b>WHEN YOU KNOW</b>	<b>MULTIPLY BY</b>	<b>TO FIND</b>	<b>SYMBOL</b>
<b>TEMPERATURE (exact degrees)</b>				
<b>°F</b>	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	<b>°C</b>

<b>SYMBOL</b>	<b>WHEN YOU KNOW</b>	<b>MULTIPLY BY</b>	<b>TO FIND</b>	<b>SYMBOL</b>
<b>ILLUMINATION</b>				
<b>fc</b>	foot-candles	10.76	lux	lx
<b>fl</b>	foot-Lamberts	3.426	candela/m <sup>2</sup>	cd/m <sup>2</sup>

<b>SYMBOL</b>	<b>WHEN YOU KNOW</b>	<b>MULTIPLY BY</b>	<b>TO FIND</b>	<b>SYMBOL</b>
<b>FORCE and PRESSURE or STRESS</b>				
<b>lbf</b>	poundforce	4.45	newtons	N
<b>lbf/in<sup>2</sup></b>	poundforce per square inch	6.89	kilopascals	kPa

**Technical Report Documentation Page**

1. Report No.		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle <b>REMEDIAL ACTION FOR FAILED POLE/BASE PLATE WELD ON HIGH MAST LIGHTING POLE (HMLP)</b>				5. Report Date December 1, 2009	
				6. Performing Organization Code	
7. Author(s) Suksawang, N., Mintz, B., Mirmiran, A.				8. Performing Organization Report No.	
9. Performing Organization Name and Address Florida International University 10555 W. Flagler Street, EC 3600, Miami, FL 33174				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. BD-015-23	
12. Sponsoring Agency Name and Address Florida Department of Transportation 605 Suwannee St. MS 30 Tallahassee, FL 32399				13. Type of Report and Period Covered Final Report March 2008 to December 2009	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract High mast lighting poles (HMLPs) were not designed for fatigue until the codes adopted more detailed procedures in 2001. Although replacement will eliminates HMLPs with fatigue cracks, these cracked poles cannot be immediately replaced as they need to be redesign, bid, and install. Removing the cracked poles is also not a solution as this will affect the lighting in the area, which compromises the visibility and safety of drivers who are travelling at night or during a thunderstorm. Thus, remedial action to temporarily prevent the cracked poles from failing prior to their replacement is needed. In this project, four repair methods have been developed and designed as remedial actions to prevent the fatigue cracks from propagating around the pole. These repair methods consist of (1) reweld of cracks, (2) welded plate stiffeners, (3) bolted stiffeners, and (4) steel jacket encasement. Results of full-scale structural testing indicate that options 2 and 3 present the best solution to temporarily remediate the cracked poles.					
17. Key Word High mast light pole, fatigue, weld crack,			18. Distribution Statement No Restriction		
19. Security Classif. (of this report) Unclassified		20. Security Classif. (of this page) Unclassified		21. No. of Pages 27	22. Price

## **ACKNOWLEDGEMENT**

The authors would like to thank the Florida Department of Transportation (FDOT) and staff for their help and support of this project: Mr. Alberto Sardinas, project manager, Mr. John Danielsen, and Mr. Marcus Ansley for their help and assistance throughout the project. Thanks to Dr. Karl Frank for provide feedback and technical comments of the recommended remedial methods. Also, the assistance of Mr. Edgar Polo, lab manager, and students, Meredith Johnson, Andres Diaz, Juan Castillo, Erik Echezabal, Michael Gonzalez, and Alexis Martinez are thankfully acknowledged.

## **EXECUTIVE SUMMARY**

The Florida Department of Transportation (FDOT) District 4 has recently detected some of its high mast lighting poles (HMLPs) with fatigue cracks problem. The fatigue cracks propagated as far as 25% of the total weld's length and were deemed to seriously compromise the structural integrity of the HMLPs, which could lead to a disastrous collapse. Thus, a decision was made by FDOT to replace all HMLPs with known fatigue cracks. Although replacement will eliminate HMLPs with fatigue cracks, these cracked poles cannot be immediately replaced as they need to be redesign, bid, and install. Removing the cracked poles is also not a solution as this will affect the lighting in the area, which compromises the visibility and safety of drivers who are travelling at night or during a thunderstorm. Therefore, a remedial action is needed to temporarily relieve the stresses in the fatigue crack to prevent the cracked poles from collapsing.

In this project, four repair methods have been developed and designed as remedial actions to prevent the fatigue cracks from propagating around the pole. These repair methods consist of (1) reweld of cracks, (2) welded plate stiffeners, (3) bolted stiffeners, and (4) steel jacket encasement. The proposed repair methods provide a quick response and implementation strategy using FDOT in-house resources (manpower and equipment), which allow the FDOT additional time to program replacement without jeopardizing the traveling public safety or impacting the work program.

A total of six HMLPs were tested—four were repaired with the four methods, one was a control cracked specimens and one was a virgin specimen. The six poles were evaluated using a full-scale structural load test. Of these four repair methods, options (2) welded plate stiffeners and (3) bolted stiffeners presented with the best performance and should be considered by FDOT as a remedial action for HMLPs suffering from fatigue fractures.

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## 1.0 INTRODUCTION

The Florida Department of Transportation (FDOT) District 4 recently had to issue a Declaration of Emergency for the replacement of sixty-one (61) high mast lighting poles (HMLPs) after the detection of fatigue cracks in the weld of the pole to the base plate. The fatigue cracks propagated as far as 25% of the total welds length and were deemed to seriously compromise the structural integrity of the HMLPs, which could lead to a disastrous collapse of the HMLPs. Figure 1 illustrates typical cracks observed on these poles. These cracks are very similar to HMLPs failure in Colorado and South Dakota where the fracture initiated at the same location, i.e., weld toe in the connection of the base plate to the pole wall, and then propagated around the pole wall until the structure collapsed. Thus, the only reasonable precaution measure for FDOT was to remove all poles at the site to prevent a catastrophic failure. The problem with the removal of these HMLPs is that lighting in the area will be affected and the visibility of the drivers who are travelling at night or during a thunderstorm will be greatly compromised. Therefore, there is a need to temporarily repair the cracked poles until they are replaced.



Figure 1. Weld Cracks

HMLPs must be designed according to the America Association of State Highway and Transportation Official (AASHTO) Specifications. However, the AASHTO Specifications do not provide accurate fatigue details specific to HMLPs, but rather to standard and general connection details commonly found on bridge superstructures. The standard details for the case of HMLPs can be classified into two categories, category E if using a full-penetration groove-weld, or a category E' if using a fillet welded socket connection. Based on previous studies, actual fatigue life performance of tested HMLPs did not meet the required minimum fatigue life categories as specified by AASHTO Specifications. Neither of the two types of HMLPs with full

penetration groove-weld or fillet welded socket satisfied the categories E and E' requirements, respectively. As the fatigue cycles accumulate, FDOT is bound to see more failures of a similar nature in the future in its existing inventory of HMLPs. Therefore, temporary remediation is needed to strengthen these HMLPs in order to buy more time for their future replacement.

## **1.1 Objectives**

The main objective of the proposed research is to provide a temporary remediation measure to strengthen the HMLPs with fatigue cracks. The proposed remediation or repair methods will provide a quick response and implementation strategy using FDOT in-house resources (manpower and equipment), which will allow the FDOT additional time to program replacement without jeopardizing the traveling public safety or impacting the work program.

Four repair methods have been identified to prevent the fatigue cracks from propagating around the pole. These methods consist of (1) reweld of cracks, (2) welded plate stiffeners, (3) bolted stiffeners, and (4) steel jacket encasement. These repaired methods were evaluated through full-scale structural load testing of sliced HMLPs.

## 2.0 BACKGROUND

HMLPs were not designed for fatigue until the codes adopted more detailed procedures in 2001 [1]. Even with the new design provisions, deficiencies exist in our understanding of fatigue under variable-amplitude loading with high intensity, such as hurricane gusts. Obviously, the frequency of occurrence of high intensity wind load is low. Nevertheless, the high intensity wind load can lead to very high stress ranges exceeding the constant-amplitude loading fatigue limits currently used in controlling fatigue in highway structural supports. In fact, researchers had observed fatigue fracture in metals roofs, offshore infrastructures, and bridges that are caused by wind-induced oscillations as a result of hurricane/tropical cyclone gusts [2-8].

The current fatigue design provisions of AASHTO resulted from the National Cooperative Highway Research Program (NCHRP) Project 10-38 [9] on fatigue design of cantilevered signal, sign, and light supports. The second phase [10] of the same project was later funded to address some areas left out from phase 1, including design example, information on loads resulting from variable-message signs, method of mitigating galloping, method of identifying structures with potential wind-induced fatigue, and guidance on design and maintenance of cantilevered supports.

While the project did provide an extensive testing program, including aerodynamic testing in a wind tunnel using a one-eighths scale model of cantilevered traffic sign structures, the project did not performed any fatigue test on the structural supports. The only fatigue tests were component level testing of anchor bolts. Furthermore, because only cantilevered traffic sign structures were tested, the effect on vortex shedding was not available experimentally, and was simply based on finite element analysis. In fact, it took six more years until a research on vortex shedding was conducted at Iowa State University [11]. Similarly, the Iowa State University research did not include any fatigue test.

The reason why no fatigue test was performed on structural supports was because all researchers were concentrated on high-cycle fatigue with very low amplitude. Wind-induced oscillations were only linked to natural wind gusts, galloping, vortex shedding, and truck gusts that can be produced at relative low wind speed as compared to hurricane gusts, so that they could use the infinite life approach. This assumption allowed them to use constant-amplitude loading data available through the testing of steel beams performed at Lehigh University [12]. The problem with this approach is that “failure could still occur if 0.05 percent or more of the stress ranges exceeded the constant-amplitude fatigue limit” [9]. In fact, the researchers of the NCHRP Project 10-38 recognized that “this is an imprecise estimate of the limit-state load range” as the structures would most likely experiences higher stress ranges during service life [9]. Based on the field monitoring of high mast light poles conducted by Phares et al. [11] at Iowa State University, the largest stress range recorded was produced by high wind speed; a clear indication that the structure would see higher load ranges than the 0.05 percent of the constant-amplitude fatigue limit when subjected to hurricane gusts.

It has been observed that fatigue in structural supports caused by hurricane gusts is a real problem. During the 2004 hurricane season with Charley, Frances, and Jeanne making landfall in Florida [13], both FPL and FDOT reported numerous fatigue failures in their lifeline infrastructure. Figure 2 illustrates some of the fatigue cracks encountered by FDOT. In the figures, the red arrows indicate fatigue crack growth retardation, which can only be explained with variable-amplitude loading. The fact that failures were spotted after the hurricane indicates the need for fundamental research to alleviate future fatigue failure under variable-amplitude loading fluctuation resulting from hurricane gusts. Therefore, in area of high wind, such as South Florida, there is a vital need to remedial cracked HMLPs before the next hurricane hit to prevent major failure that may directly or indirectly lead to a loss of life.

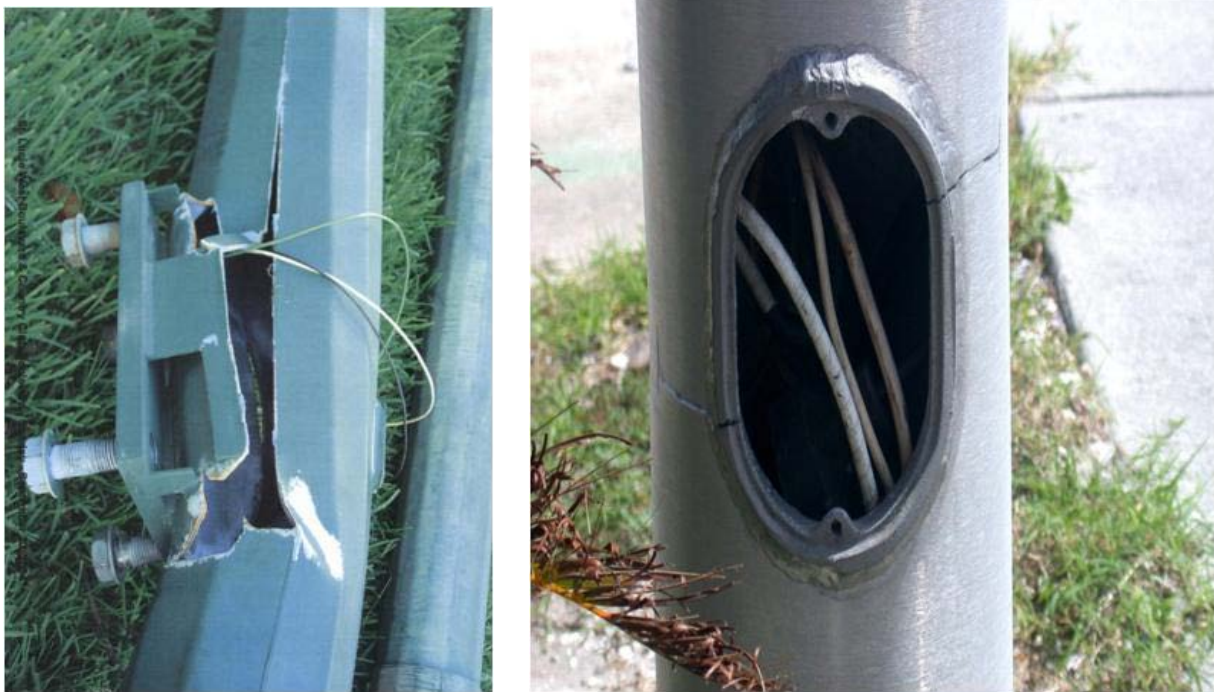


Figure 2. Inspected fatigue failure of mast arm and light poles after 2004 hurricane season  
(Photographs from Sardinias et al., 2009 [13])

### 3.0 METHODOLOGY

#### 3.1 Repaired Method

Four repair methods have been developed and designed as remedial actions to prevent the fatigue cracks from propagating around the pole. These repair methods consist of (1) reweld of cracks, (2) welded plate stiffeners, (3) bolted stiffeners, and (4) steel jacket encasement. All repair methods were installed using FDOT in-house resources (manpower and equipment). The details of these repair methods are shown in detail in Appendix A. Figure 3 illustrates the repair methods as they were installed.



Figure 3. Installed Specimens (Clockwise from top left: Reweld, Steel Jacket, Welded Plate, Bolted Plate)



The reweld of cracks repair method was adopted from the contractor who insisted on using this approach to temporarily remediate the fatigue cracks in the HMLPs. The reweld of cracks was a very simple method, where the contractor simply provide extra fillet weld at the area where cracks were observed. Similar method was recommended by Dr. Karl Frank from University of Texas for Texas HMLPs. However, there are significant differences between the welding detail recommended by Dr. Frank and the one performed in this project on the repaired poles. The detail suggested by Dr. Frank requires the existing weld to first be removed to minimize any internal cracks within the existing weld. The welder should also perform multiple weld passes with surface wire brushed in between. The cracks need to be checked using magnetic particle tests or other nondestructive methods to ensure that the cracks are properly closed. Furthermore, the Texas HMLPs have a 3 in base plate, whereas the FDOT HMLPs have a 1 in base plate. Thus, in order for this repair method to perform well, quality control and quality assurance as well as training is needed.

The welded plate stiffeners consist of six  $\frac{3}{8} \times 3 \frac{1}{2} \times 16$  in triangular steel plates welded to the sides of the HMLPs. The FDOT welder favored this method as it was easy to install. The welding took a few hours and could be done without removing any bolts. However, the utilities would have to be shielded in the field to prevent damage and the welding needs to be of a better quality than the one performed here as evidence by rough welds profile and the undercutting. Additionally, Dr. Frank also recommended that the galvanizing should be cleaned off the surface before welding. This can be done using a flap type sanding disk, which will remove the coating and not grind into the mast.

The bolted stiffener consists of two  $\frac{3}{8} \times 3 \frac{1}{2} \times 16$  in triangular steel plates welded to a steel plate backing that can be bolted onto the HMLPs. Six of these bolted stiffeners were installed on the cracked HMLPs. According to Dr. Frank, this repair method is a promising retrofit and should be able to handle fatigue. However, because of the unique dimensions of the HMLPs, installation becomes a challenge in the field. One problem encountered during the installation was the metal backing may not lay flat against the mast. Another problem was the holes on the mast were difficult to drill. The FDOT staff had to torch the holes rather than the recommended drilling. The torched surface prevents the bolt and nuts from being fully engaged. The third problem is the back plate or the panel mount inside the HMLPs did not allow easy access to the bolt locations. However, all these problems could be resolved through training as well as using twist off bolts.

The steel jacket was an expensive option that proved to be impractical for installation. The jacket consist of two steel half pipes bolted together to form a jacket that encases the mast and the base welded to the base plate. The gaps between the jacket and mast were sealed using Chockfast Orange. The problem with this repair method was the hand hole of the HMLPs was very low, which requires the half pipe to have a U-opening. The U-opening was so large that lead the leakage of Chockfast Orange. Furthermore, the fact that the mast may be different sizes makes it impossible to mass produce the sleeve. Because the installation of this repair method was not possible under field condition, the specimen was not tested.

### 3.2 Test Setup

Figure 4 shows the test setup and specimen used in the test. The load was applied at approximately 53 inches from the location of the weld. At the load point, the specimen was grouted to prevent local buckling. The specimen was rotated such that the weakest section (the location with the highest crack length) is on top to simulate the worst case scenario. In the field, the wind can come in any directions and the failure mode should govern at the weakest point. The pole was instrumented with strain gages (Figure 5), string pots and potentiometers (Figure 6), to monitor the specimen's stresses, deflection, and crack growth, respectively. The load was applied until crack propagates or as the mast yielded. Data was collected by a Vishay data acquisition system.



Figure 4. Test Setup





Figure 5. Strain Gage Installation

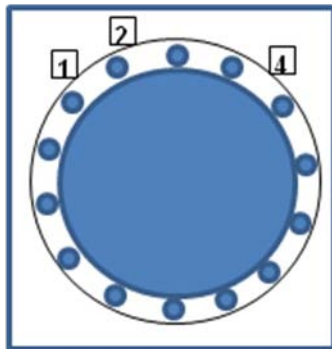


Figure 6. Potentiometer Placement

### 3.3 Test Summary

All specimens were tested as a cantilever to failure, which was determined by the strain gages and/or significant crack growth. Figure 7 illustrates a failed specimen after loading to failure. The loading was either applied using displacement control using a loading rate of approximately 0.06 in/min (a value that was approximated from previous load control conditions) or load control at a rate of 25 or 50 lbs/s.

Table 1 summarizes the poles' numbers that correspond to each retrofit type and the ratio of cracked circumference to uncracked circumference, according to the report issued by MACTEC in 2007. Overall, all specimens had similar crack ratios between 0.26 to 0.38, with the exception of the control cracked specimen that only had a crack ratio of 0.05. The reweld of crack specimen did not have any MACTEC report on the level of crack it had.



Figure 7. Cracking in the Toe Weld

Table 1 Specimen Pole Numbers and Crack Ratio

Pole Number	Retrofit Type	Ratio of Crack
86P335	Reweld	Not Reported
86P399	Cracked Control Specimen	0.05
86P338	Bolted Stiffener	0.38
86P337	Welded Stiffener	0.27
86P317	Steel Jacket	0.26
86P329	Uncracked Control Specimen	0.00

## 4.0 RESULTS

Figure 8 illustrates the moment versus maximum stresses curve. The stresses were taken from the top strain gages, where the maximum positive moment occurs. It should be noted that the steel jacket retrofitted specimen was not tested due to the impracticality with the installation of the jacket onto the pole. Overall, the bolted and welded stiffeners performed the best. In fact, for the welded plate stiffener, the test was stopped after the mast had yielded and the moment reached the design moment of 140 ft-kips. No cracking between the base plate and the steel mast was observed. Nor was there any cracking in the weld around the plate stiffener.

The bolted plate stiffener performed very well exceeding the capacity of the controlled specimen until the bolt began to slip at a moment of 90 ft-kip. Once the bolts were loosened and disengaged cracking at the base plate occurred. The reason for this as explained earlier is two folds: (1) torched holes and (2) regular structural bolts were used instead of twist off bolts to ensure no slippage in the connection. If the slippage can be eliminated with twist off bolts, one advantage of this repair method over the welded stiffener is the ease of inspection. The engineer simply has to verify the tightness of the bolts.

Initially, the rewelded specimen demonstrated slightly better performance than the cracked specimen in term of stiffness, but after the moment reaches 60 ft-kip, cracking was observed. In fact, the specimen cracked at the same moment as the controlled cracked specimen. Therefore, reweld of cracks should not be recommended as a remedial action in the field. It should be avoided all together because it is impossible to inspect without resourcing to expensive non-destructive tests as there is no way to visual inspect the cracks covered by the reweld.

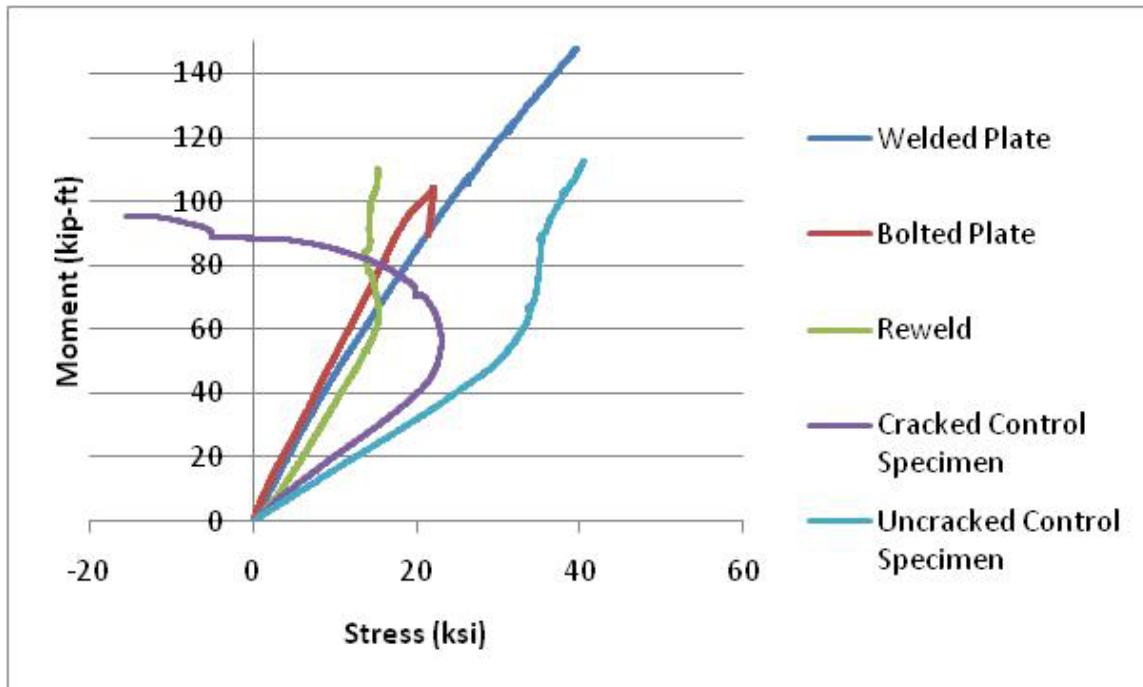


Figure 8. Moment Versus Maximum Stress

## 5.0 CONCLUSION AND RECOMMENDATION

The following conclusion and recommendation can be made from this project:

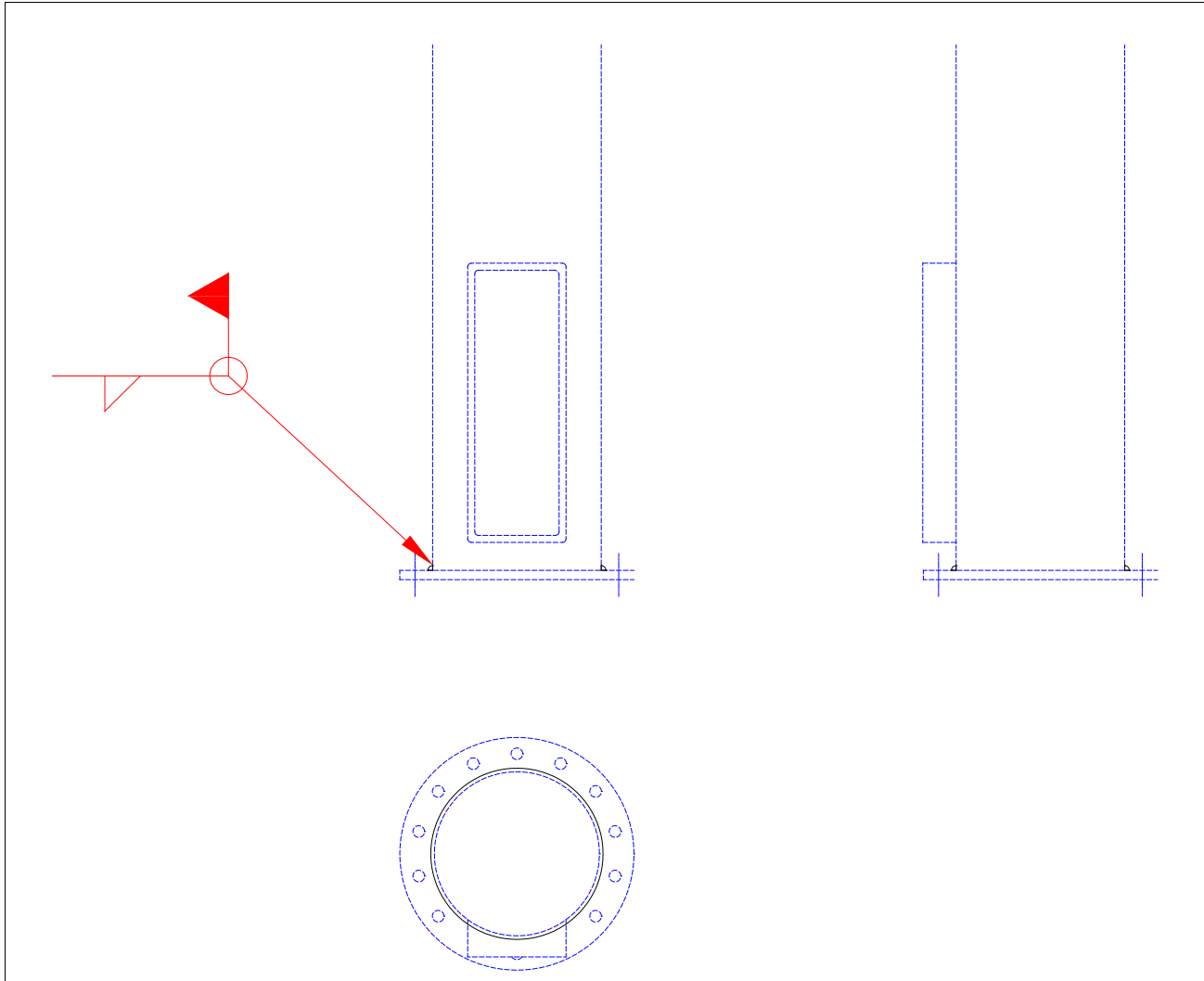
1. The welded and bolted plate stiffeners are recommended as temporary remedial action for cracked HMLPs. However, the bolted plate stiffeners will be easier to inspect and install.
2. A slotted hole on the base plate of bolted stiffener should be used to allow the stiffener to be located against a flat on the mast. A plate washer should be used between the nut and the slotted hole to provide bearing for the nut.
3. The holes in the mast for the bolts attaching the stiffener to the mast need to be drilled instead of torched. The surface should also be cleaned from oil before installing the stiffener to prevent lubrication of the faying surfaces of the bolted connection. The drilled hole will provide better fatigue performance and prevent the slag build up around the burned hole.
4. A twist off bolt should be used for the bolted stiffeners to facilitate a one sided installation and to ensure no slippage.
5. It is very important to clean the galvanizing off of the surface before welding. This can be done using a flap type sanding disk which will remove the coating and not grind into the mast.

6. The rough weld profile and undercut in test specimens do not meet the current bridge welding specifications. Care should be taken when welding the plate stiffeners.

## 6.0 REFERENCES

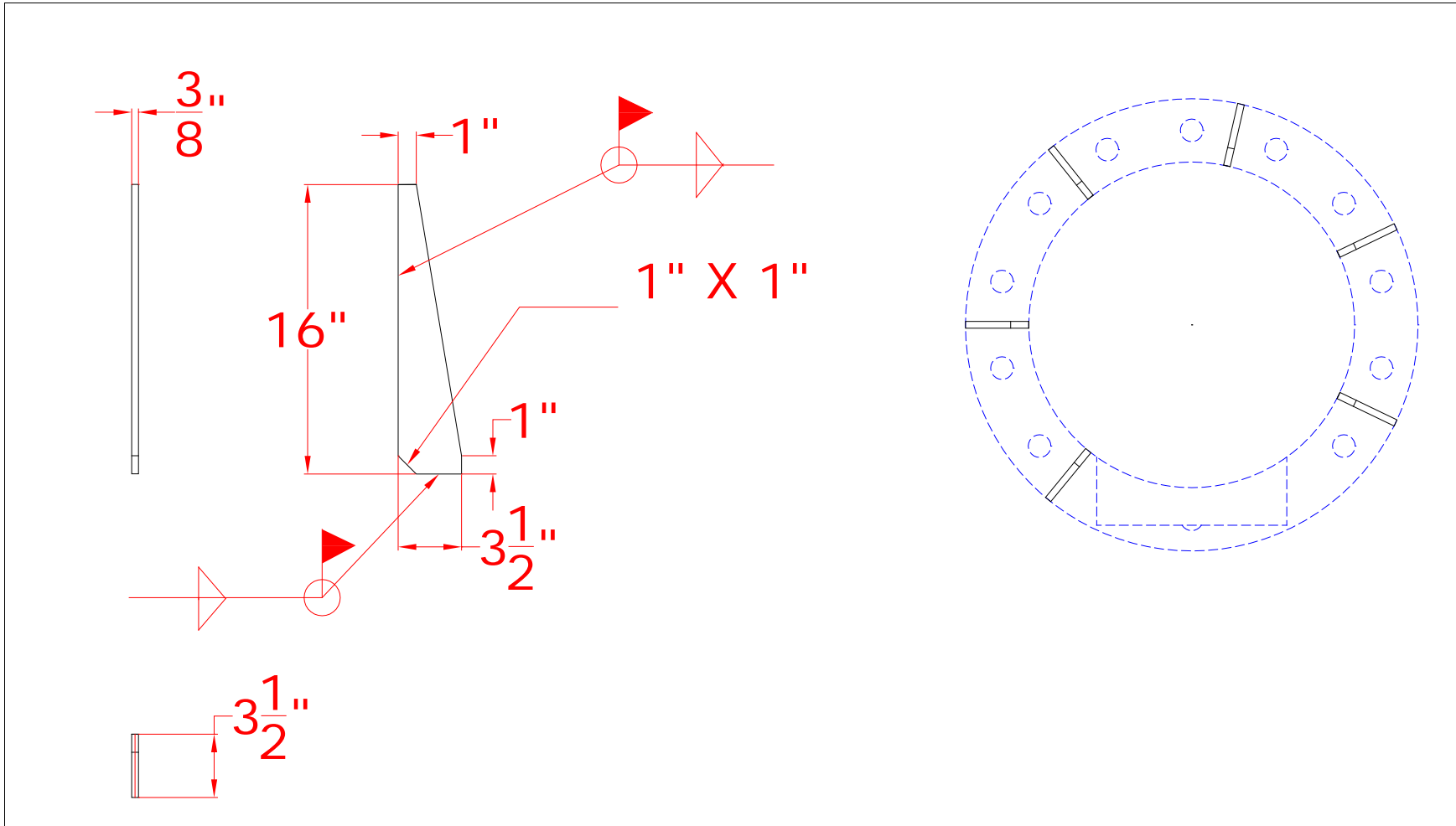
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## **APPENDIX A: RETROFIT DETAILS**

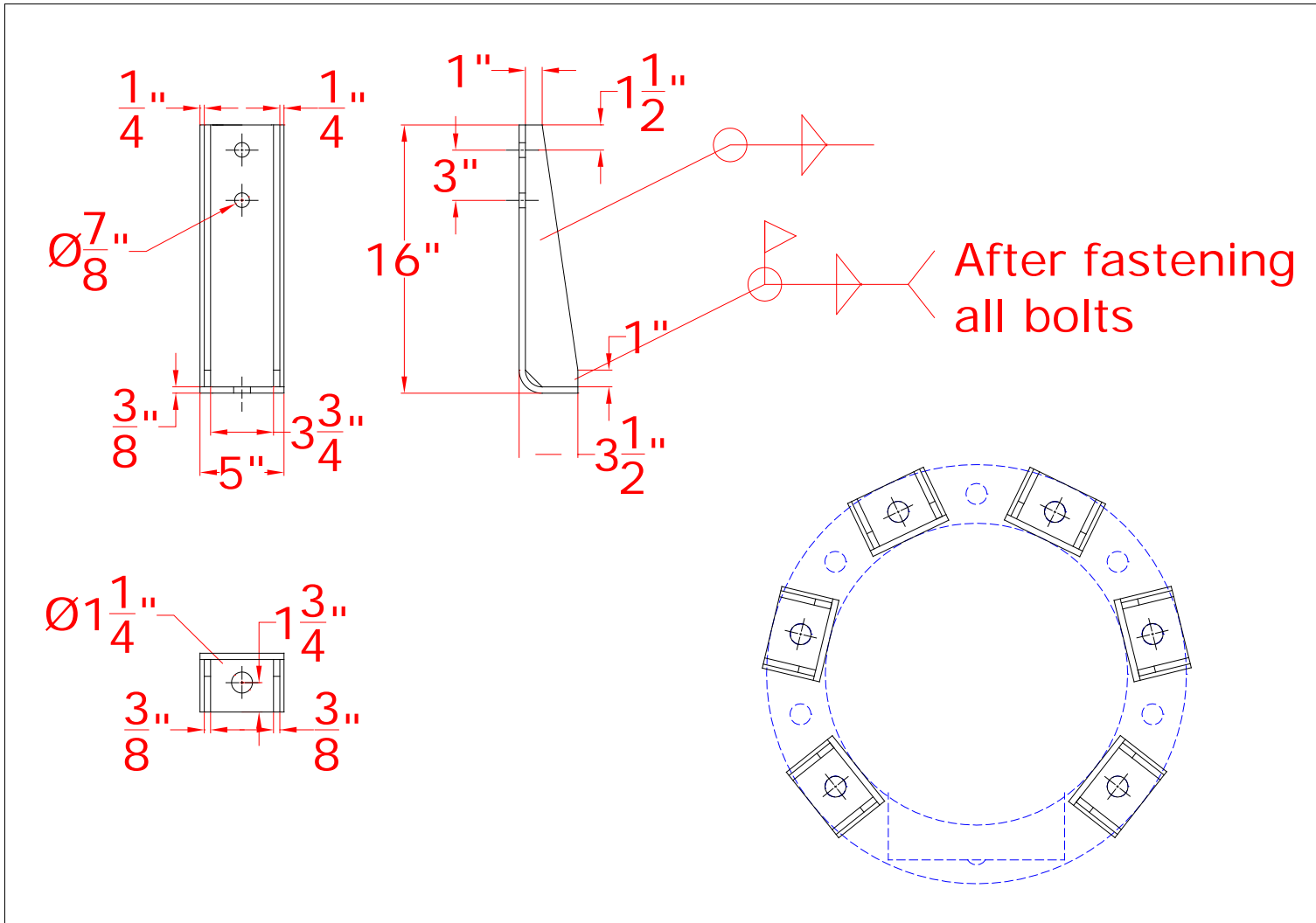


Option 1. Reweld of cracks

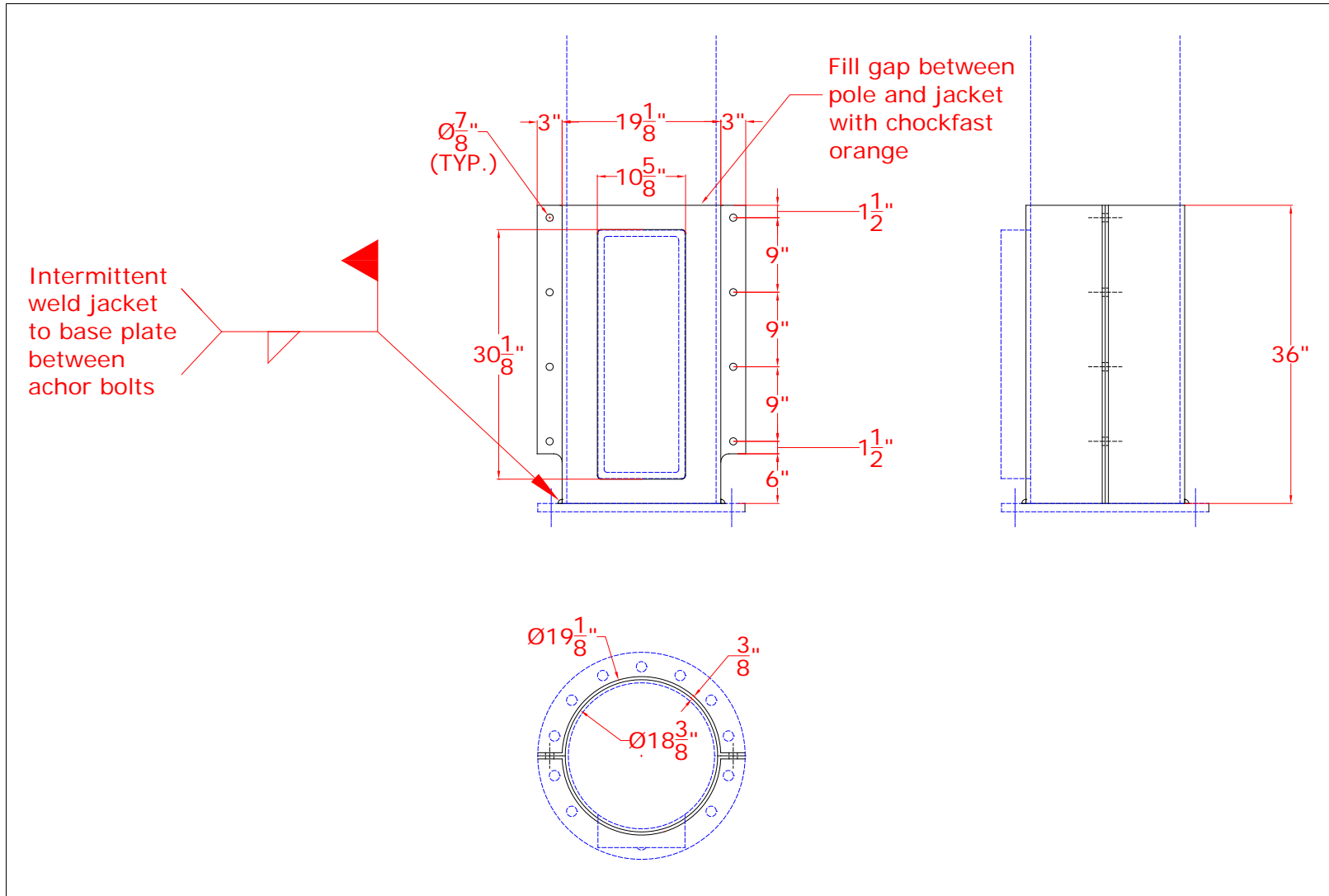




Option 2. Welded Plate Stiffeners



Option 3: Bolted Stiffeners



Option 4. Steel Jacket