Research Project 9-1526 / TPF-5(116)

"Investigation of the Fatigue Life of Steel Base Plate to Pole Connections for Traffic Structures"

A Pooled Fund Study

Project Update

January 2007

Introduction

With the completion of fatigue testing, it was felt that it was important to inform those involved with the project of the progress that has been made to date. In addition, this update will also serve as a general overview of the project and conclude with observations and recommendations.

Description of Test Specimens

Based on the testing matrix that was developed in the meeting of representatives in the pooled fund, specimens were designed in accordance with various design drawings from the represented states. The testing matrices for the 10" round mast arms and the 24" high mast poles can be found below in Tables 1 and 2, respectively. Note that it was agreed upon at the meeting to use 7 gage, galvanized, Gr. 50 steel for the 10" mast arms and 5/16" galvanized steel for the 24" high masts.

Table 1: Test Matrix for 10" Round Mast Arms

Base Plate Size	# of Specimens			
	External Collar	No Collar	Calif. Weld Spec	Full Penet. Weld (WY Spec.)
1 3/4"	2	2		
2"	2	2	2	2
3"		2		

Table 2: Test Matrix for 24" High Mast Poles

Base Plate Size	Weld Type	# of Specimens	
		8 Bolts	12 Bolts
1 1/2"	Fillet	2	2
2"	Fillet	2	2
	Full Pen.	2 (WY)	
2" (with Stools)	Fillet	2	
3"	Fillet	2	
	Full Pen.		2 (TX)

These testing matrices were designed to investigate several variables and their effects on the fatigue life of the traffic structures. The variables included in the testing matrices addressed several issues regarding the fatigue performance of the poles. Issues concerning the fatigue performance of the 10" round mast arms included:

- The influence of base plate thickness upon the fatigue strength of fillet welded socket connections and external collar connections.

•Comparison of the fatigue strength of external collar connections, socketed connection, and full penetration welded connections when using the same base plate thickness.

Issues concerning the fatigue performance of the 24" high mast poles included:

•The influence of base plate thickness on the performance of socketed connections.
•The influence of the number of anchor bolts used in base plates.
•Compare the performance of a full penetration weld with the fillet welded socket connection when using a 2 in. base plate.
•Evaluate the fatigue performance of the anchor bolt stool connection in high mast lighting poles similar to those used in the state of Iowa.

Description of Test Setup

The fatigue testing of both the 10" round mast arms and the 24" high mast poles utilized a system based on a simply supported beam analogy with a centrally applied load. In this setup, two specimens are coupled at the base by means of a loading box with their ends connected to reaction supports. Load is then applied by a hydraulic actuator until the desired stress range at the critical section is reached. Note that one of the reaction supports must provide 2 degrees of freedom in order for the system to be determinant and not introduce an axial force on the specimens. The test setup for the mast arms and the high mast lighting poles can be seen in Figures 1 and 2 below, respectively.

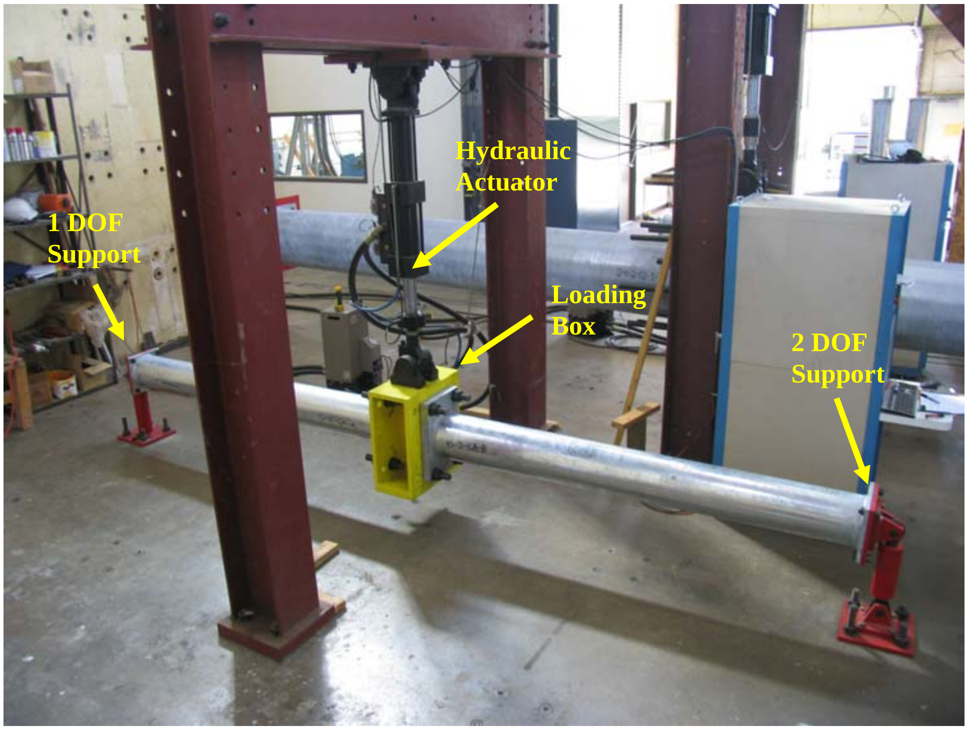

Figure 1: Test Setup for 10" Mast Arms


Figure 2: Test Setup for 24” high mast poles

The test setup for the 24” high mast lighting poles is almost identical to the one used for the 10” mast arms; only on a much larger scale. The small test setup has a total length of 16’ from one reaction support to the other while the large setup has a total length of 32’. One of the few differences between the two setups was the way in which the specimens were bolted to the loading box. For the small test setup, washers were placed in between the base plate and the loading box to eliminate the possibility of a warped base plate from introducing unwanted stresses. For this same reason, leveling nuts were used for the 24” high masts in the large test setup. The leveling nuts can be seen in Figure 3 below. Note that this picture was taken during installation and the specimen is not yet bolted to the loading box.

Figure 3: Leveling nuts used for base plate to loading box connection in large test setup

Testing Progress to Date

The specimens were subjected to cyclic loading that would produce a stress range at the pole to base plate connection of 12 ksi for the 10” mast arms and 10 ksi for the 24” high mast poles. The high masts have a reduced stress range due to limitations from capacity of the system. Failure of each specimen was constituted by a 10% drop in applied load. Once a 10% drop was detected by the actuator controller, the system would shut itself down and display the number of cycles the specimens had reached.

Fatigue testing on the 10” mast arms has completed. Early testing speeds were limited by a resonance problem in the external hydraulic pump. However, with a simple retrofit, testing speeds were able to be increased from 4 Hz to 9 Hz.

Fatigue testing on the 24” mast arms has also completed. Due to very poor performance, which will be discussed in following sections, testing at a rate of 1.75 Hz was fast enough to complete testing in a more than reasonable time.

Testing Results

10” Mast Arms

Table 3 below summarizes the results from the fatigue testing of the 10” mast arms. Each specimen was given a name based on its base plate thickness and connection type.

Table 3: Fatigue testing results for 10” mast arms

Base Plate Thickness (in)	Weld Detail	Specimen(s) Name	Failure (10% Drop in Load)
1.75	Socket Fillet Weld	10-1.75-S-A	Unable to Test to Failure
1.75	Socket Fillet Weld	10-1.75-S-B	142,857
1.75	External Collar*	10-1.75-EC-A(2)	2,345,896
1.75	External Collar*	10-1.75-EC-B(2)	5,755,111
1.75	External Collar	10-1.75-EC(1)-A	6,206,754
1.75	External Collar	10-1.75-EC(1)-B	3,304,490
2	Socket Fillet Weld	10-2-S-A(2)	210,793
2	Socket Fillet Weld	10-2-S-B(2)	622,928
2	External Collar*	10-2-EC-A(2)	3,939,099
2	External Collar*	10-2-EC-B(2)	6,927,606
2	External Collar	10-2-EC(1)-A	5,384,143
2	External Collar	10-2-EC(1)-B	8,247,664
2	Butt Weld (WY Detail)	10-2-WY-A	4,997,925
2	Butt Weld (WY Detail)	10-2-WY-B	7,527,441
2	CA Socket Connection	10-2-CA-A	253,657
2	CA Socket Connection	10-2-CA-B	310,352
3	Socket Fillet Weld	10-3-S-A	Unable to Test to Failure
3	Socket Fillet Weld	10-3-S-B	792,576

* Ultrasonic testing specified on welds during manufacturing

One will notice that for three of the specimens, the fatigue life states that the specimens were “Unable to Test to Failure.” Two of these specimens had one thing in common: the weld toe seemed to have been ground smooth during manufacturing. Grinding the weld toe reduces the angle with which the weld comes into contact with the pole wall. This has a significant effect on fatigue performance since it reduces the stress concentration at the critical location of the weld toe. Figure 4 below shows a weld from one of these specimens.

It should also be noted that two sets of the specimens with the external collar detail were sent from the manufacturer. It was initially believed that the first set of specimens with the external collar detail contained welds with defects. As a result, an additional set of specimens with the external collar detail were manufactured with ultrasonic testing specified on the welds. Testing revealed that there were no defects in the welds on the initial set of external collar specimens. Both sets of external collar specimens had similar performance.

Figure 4: Grinding of the weld toe

The fatigue performance of the 10” round mast arms is plotted on the AASHTO design curves below. Color and shape codes are used so that comparisons can be inferred just by looking at the plot.

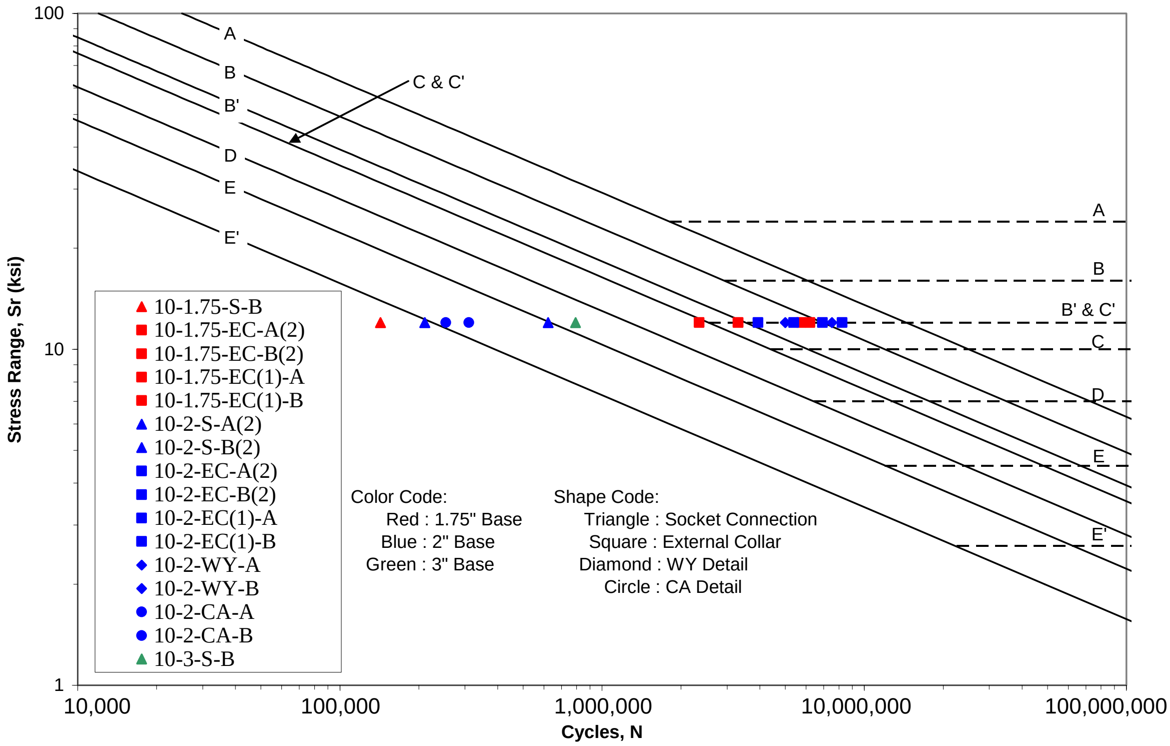

Figure 5: Fatigue performance of 10” mast arms

Observations made after inspection of the plotted values on the AASHTO design curves include:

1. Increasing the base plate thickness increases fatigue life
2. The California detail performs about the same as a socketed connection
3. The External Collar and Wyoming details achieved desirable performance

From these observations it was noticed that fatigue performance seems to be influenced to some degree by the stiffness of the base plate to pole connection. For example, the Wyoming detail did not utilize a socketed connection. Rather than cutting a large hole in the base plate to fit the pole, it had a smaller hole that was needed only to drain out molten zinc for galvanizing and weld the inside back-up bar. Having a smaller hole increased the base plate stiffness. The external collar detail also displayed an increased stiffness due to the effective increase in cross section at the pole to base plate connection. Both of these connection types performed extremely well in relation to other connection types.

24" High Mast Poles

Table 4 below summarizes the results from the fatigue testing of the 24" high mast poles. Similar to the smaller specimens, each 24" specimen was given a name based on the number of bolts it used, its base plate thickness, and its connection type.

Table 4: Fatigue testing results for 24" high mast poles

# Bolts Used	Base Plate Thickness (in)	Connection Detail	Specimen(s) Name	Failure (10% Drop in Load)
8	1.5	Socket Fillet Weld	24-1.5-8-S-A,B	13193
8	2	Socket Fillet Weld	24-2-8-S-A,B	46772
8	2	Butt Weld (WY Detail)	24-2-8-WY-A,B	133809
8	2	Stool Base	24-2-8-SB-A	785058
8	2	Stool Base	24-2-8-SB-B	483314
8	3	Socket Fillet Weld	24-3-8-S-A,B	147550
12	1.5	Socket Fillet Weld	24-1.5-12-S-A,B	27,977
12	2	Socket Fillet Weld	24-2-12-S-A,B	143,214
12	3	Butt Weld (TX Detail)	24-3-12-TX-A	236,154
12	3	Butt Weld (TX Detail)	24-3-12-TX-B	327,487

The fatigue performance of the 24" high mast poles is plotted on the AASHTO design curves below. Color, shape, and shading codes are used so that comparisons can be inferred just by looking at the plot much like the plot made for the 10" mast arms.

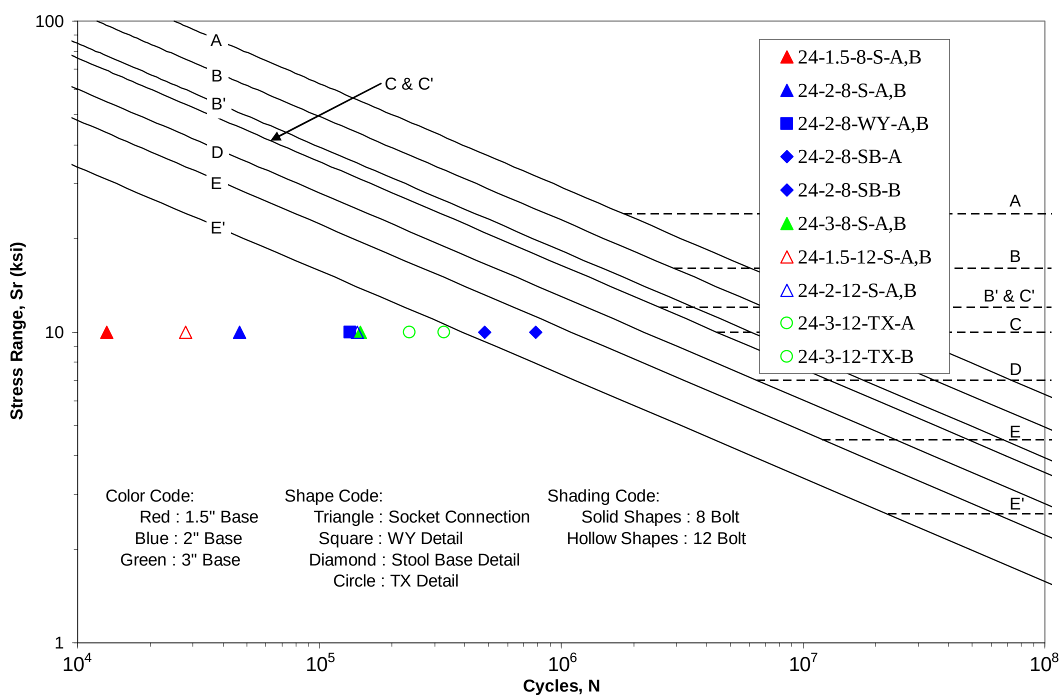

Figure 6: Fatigue performance of 24" high mast poles

Observations that can be made from this plot include:

1. Increasing the base plate thickness increases fatigue performance when using a socketed connection.
2. Increasing the number of anchor bolts increases fatigue performance.
3. The stool base detail had the best fatigue performance followed by the TX detail, WY detail, and then the socketed connection.

Much like the 10” mast arms, fatigue performance of the 24” high mast poles seems to be influenced by the stiffness of the base plate to pole connection. Increasing the connection by means of base plate thickness, number of anchor bolts, or connection type increases fatigue life to some extent. However, overall performance of the high mast poles was very poor. Only the stool base connection detail met the minimum requirement of E’ in the AASHTO design code. An interesting note is that the stool base detail has the potential to be developed as a retrofit for existing structures.

Further Testing and Research

Further research will include Finite Element modeling to both confirm experimental test results and to investigate other relationships regarding fatigue life such as pole wall thickness or pole diameter. Time permitting, static tests will be performed on the 24” high mast poles to determine ultimate capacities. It is questionable that full strength of the section can be developed with such flexible base plate to pole connections.

Further experimental tests for the 10” mast arms should confirm the performance of the external collar and Wyoming detail and investigate the use of larger base plates. Additional experimental tests for the 24” high masts might include a detail that utilizes an external stiffening collar and thicker base plates such as those used in Texas. Other 24” specimens might include modifications to the Wyoming or stool base details. Drawings for potential Phase II specimens are being developed.

Conclusions

Fatigue performance of the 10” mast arms with socketed connections remains around or below category E’ according to the AASHTO design curves. The external collar and Wyoming details performed far superior to other details reaching as high as Category B’ on the AASHTO design curves. Recommendations for an immediate fix would be to either use thicker base plates or utilize details similar to those used in the external collar or Wyoming details.

Fatigue performance of the 24” high mast poles is alarmingly poor. Only one connection detail met the required Category E’ fatigue performance. Smaller base plate thicknesses such as 1.75” and 2” should no longer be used in the high mast poles. An immediate fix would be to increase base plate thicknesses or increase the number of anchor bolts used. Both of these solutions would increase the stiffness of the base plate to pole connection.