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STATIC AND DYNAMIC PROPERTIES OF ANCHOR BOLTS FOR SIGN SUPPORTS
(Final Report)

MICHIGAN DEPARTMENT OF TRANSPORTATION

MATERIALS and TECHNOLOGY DIVISION

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Static and dynamic
properties of anchor bolts
for sign supports

STATIC AND DYNAMIC PROPERTIES OF ANCHOR BOLTS FOR SIGN SUPPORTS
(Final Report)

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SUMMARY

The experimental work performed for this report is a continuation of the research done under Research Project 77 F-153 and reported on in 1982 (1). In the additional work reported on here, dynamic loading tests were performed on a group of 25 bolts. Ten of these bolts were galvanized, five were plain steel of the same steel stock as the galvanized, five were stainless steel clad, and five were made of solid stainless steel. Thread interference information was obtained for all nut-bolt combinations, and proved to be within specification.

The initial study showed that the fatigue life of a standard carbon steel bolt is reduced when that bolt is galvanized to provide corrosion protection (1). The results of this additional work confirms those of the earlier report. In addition, the results show that there doesn't appear to have been any loss of fatigue life due to the configuration of the first testing fixture. Both the solid stainless and the stainless clad anchor bolts exhibited extremely high fatigue life. When subjected to the same stress range as the galvanized and plain bolts the solid and clad stainless steel bolts did not fail even after 7,000,000 cycles. The stress range had to be increased twice to a final level of 183 percent of the initial value to reduce the fatigue life of either bolt to below the mean level of the galvanized bolts.

Conclusions

The earlier findings showing that galvanizing reduces the fatigue life of anchor bolts were confirmed.

All anchor bolts tested (galvanized, plain, solid stainless steel, and stainless steel clad) exceeded the mechanical requirements of the current MDOT Specification 8.07.14, with the exception of the elongation at break of the plain steel bolts tested (see Appendix).

The fatigue life of the galvanized and plain steel bolts fell between the two groups tested (those purchased from an independent source and those from the MDOT warehouse) in the original report. This seems to indicate that no significant bending loads were introduced by the testing fixture used in the original experiment.

The average fatigue life of the solid stainless steel and stainless steel clad bolts exceeded that of the galvanized bolts (the bolts presently required by MDOT) by more than an order of magnitude. Although only limited testing was done, when the 1-5/8-in. nominal diameter stainless steel bolts were subjected to a higher load, their average fatigue life exceeded the fatigue life of the 2-in. diameter bolts tested in the original report (1). It is possible that the 1-5/8-in. nominal diameter stainless steel bolts could be substituted for the 2-in. diameter bolts now in use.

The use of stainless steel bolts is not cost competitive even if smaller diameter stainless steel bolts could be substituted for the 2-in. galvanized bolts.

INTRODUCTION

Background

In the early 1970's there had been a series of anchor bolt failures on cantilever sign structures. Some of the bolts that failed were older plain carbon steel bolts on small cantilever structures that failed in fatigue due to section loss brought about by long term corrosion; but some of the fatigue failures were in the galvanized bolts on large supports that had been installed only a few years before. A research project was initiated to test, among other things, the fatigue life of galvanized bolts, and to compare it with the plain steel bolts used previously. During this investigation it was discovered that if a bolt was galvanized its fatigue life was reduced. As a result of this earlier investigation, design bolt sizes were increased to reduce stresses. A program also was developed to test all anchor bolts in service on cantilever sign structures to determine their condition. The field inspections were done by the M&T Structural Services Unit. Several cracked bolts were found and removed from service. One of the earlier report's recommendations was that, "Further work should be done to identify corrosion resistant anchor bolts that are less susceptible to fatigue" (1). The stainless steel clad and the solid stainless steel anchor bolts that were tested in this investigation are advertised as having both a high corrosion resistance and a long fatigue life.

There was some concern that the fixture used in the cyclic testing of the anchor bolts in the initial study could have induced some bending loads in the bolts, thereby reducing their fatigue lives. Bending loads do not normally occur in properly installed anchor bolts. There was evidence, however, from the field failures that some bolts had not been placed in proper alignment in the footings, and indeed had been subject to bending loads that caused early failure. Based on this information, plans were changed by the Design Division to require considerable improvement in the support and positioning of the anchor bolts during construction. It had also been evident from the failure analysis that the nuts had loosened and the bolts had fractured sequentially, several having failed before the structure tipped or fell.

Evaluation of the clad and solid stainless steel anchor bolts, combined with concern over the effect that the old fixture may have had on the fatigue life of the anchor bolts, were the primary reasons for initiating this investigation.

Objectives

The following specific objectives were to be realized:

1) determine the fatigue life of stainless steel clad and solid stainless steel anchor bolts,

2) compare the physical properties (corrosion, fatigue life, strength, etc.) of the stainless steel and stainless steel clad anchor bolts with those of the galvanized bolts now specified,

3) design and build an improved testing fixture, and

4) determine if the configuration of the testing fixture used in the initial investigation introduced bending loads into the anchor bolts tested that could have significantly reduced the fatigue life of the bolts.

Scope

In order to realize the above objectives, fatigue evaluations were done on 25 bolts. Ten galvanized and five plain bolts, each 1-1/2-in. diameter, and of the same medium carbon steel were included, as well as five clad stainless steel and five solid stainless steel bolts of nominal 1-5/8-in. diameter.

Nine ASTM E8 (0.505 tensile) tests were performed. Two full-sized tensile tests were performed on the clad bolts to get a better idea of how the composite system responded in tension. Samples were taken from each group of bolts for analysis of chemical composition. Thread interference measurements were taken for all bolt-nut assemblies.

TEST PROCEDURES AND RESULTS

Procedures

Fatigue Life - The Materials Testing System (MTS) in the Structural Research Laboratory was used to load the specimens cyclically (Fig. 1).

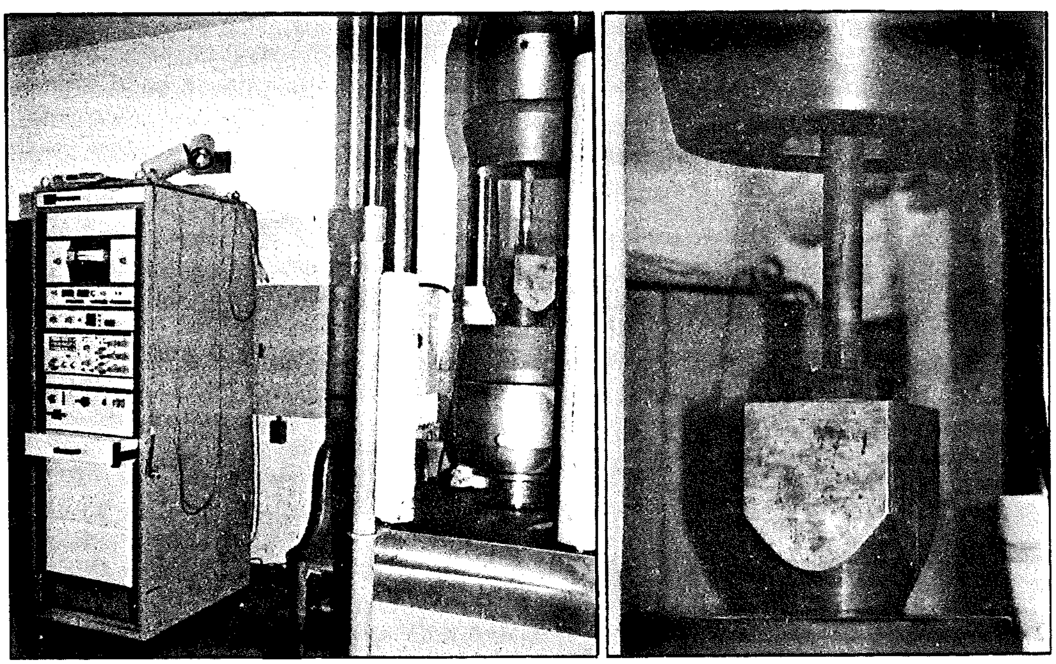

Figure 1. Cyclic testing of samples in the MTS 200-kip capacity load frame. Note loading fixture.

A new loading fixture was developed and built by the Laboratory's machine shop since the first report was published, to eliminate any possibility of the introduction of bending loads into the test specimens. The initial stress range was set at +23.19 (tension) to -8.86 ksi (compression) for all the bolts. (A loading range of +34,000 to -13,000 lb was used for the galvanized and plain bolts and +38,500 to -14,700 lb was used for all the clad and solid stainless steel bolts. The difference in initial load range between the two groups is due to the slightly larger diameter of the English made bolts due to metric sizes.) The stress and load ranges for both the stainless steel clad and solid stainless steel bolts had to be increased after the first two tests for each bolt went more than 7,000,000 cycles with no failures. Further testing was done at stress ranges of +29.94 to -11.44 ksi (29 percent increase over initial) and +35.78 to -22.89 ksi (83 percent increase over initial; load ranges were +49,700 to -19,000 lb and +59,400 to -38,000 lb). All tests were run at six cycles per second to prevent a heat build-up in the specimen.

Mechanical and Chemical Properties - Nine ASTM E8 (0.505 tensile) tests were performed with the MTS equipment. Three of the tests were performed on the base material of the galvanized bolts, three on the plain steel bolts, two on the solid stainless steel bolts, and one on the base material of a stainless steel clad bolt. This particular test reveals the ultimate and yield strengths, the percent reduction of area and the percent elongation of the material tested. Two full-sized tensile tests were performed on the stainless steel clad bolts to get a better idea of how the composite material reacts in tension. These tests were performed on a 600,000-lb Universal testing machine since the loading required for the specimen to fail surpasses the capacity of our MTS equipment. This test also revealed the ultimate and yield strengths, the percent reduction of area, and the percent elongation. One sample was taken from each group and sent to an independent laboratory for analysis of each material's chemical composition. The only exception to this is that two samples were taken from the stainless steel clad bar, one from the base material and one from the stainless steel used in the cladding.

Closeness of Fit - Every bolt assembly tested was measured prior to testing for closeness of fit, or thread interference. The value for thread interference is derived by subtracting the minor diameter of the nut from the major diameter of the bolt (Fig. 2). Each value represents the average of measurements at three different locations along the thread.

Results

Fatigue Experiments - The first two groups of tests will be considered together. The first test group involved ten 1-1/2-in. diameter galvanized bolt assemblies and the second consisted of five 1-1/2-in. plain steel bolt assemblies. The cyclic stresses used were 100 percent of the design live load. The results, recorded in Table 1 and shown graphically in Figure 3, indicate that the plain steel bolts had a number of cycles to failure approximately 2-1/2 times that recorded for the galvanized bolts, based on either the average or the median.

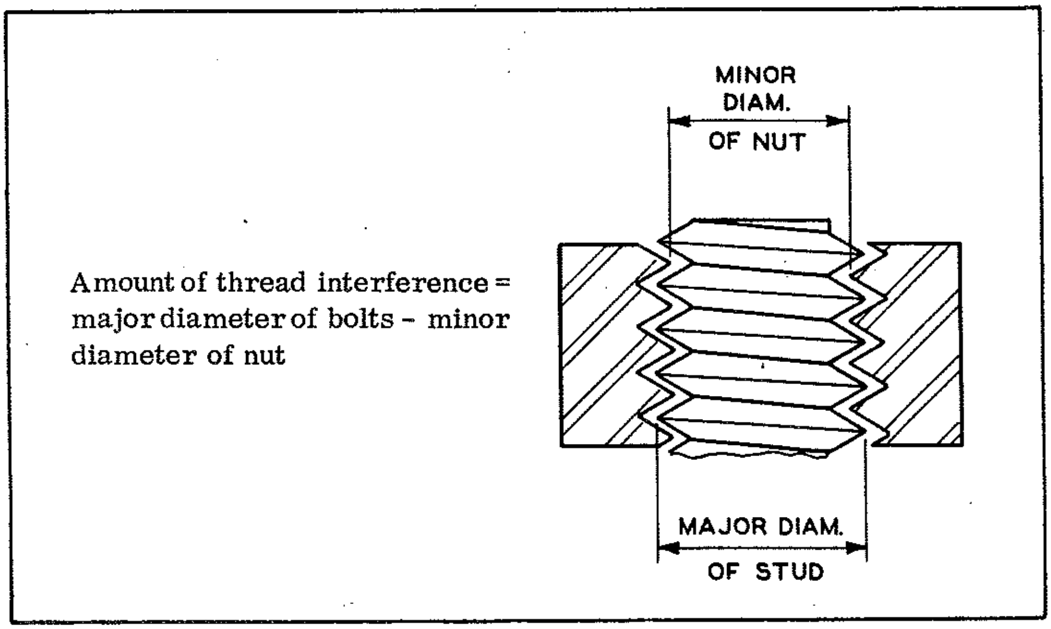

Figure 2. Method of determining thread interference.

The fatigue life values recorded for the galvanized and the plain bolts fall between those of the two samples tested in the original report (those purchased from an independent source and those from the MDOT warehouse). The shape of the bolt thread root (rounded or sharp) was the differentiating factor between the two test groups in the earlier report. The longer-lived bolts (independent source) had a rounded thread bottom while the other bolts (from the MDOT warehouse) had a flat thread bottom with sharp corners at each side. The bolts tested in this report were machined so that the bottom of the threads were somewhat flat with the corners beginning to round. This is one of the reasons that the results fell between the two samples from the initial report.

These results also show that there was no significant reduction in the fatigue life due to the configuration of the initial testing fixture. If the bolts just tested had recorded a significantly higher fatigue life than those of the previous test, the testing fixture would have been suspect.

Five solid stainless steel and five stainless steel clad bolt assemblies were tested. The results are recorded in Table 1. All of these bolts were manufactured in England and nominally 1-5/8 in., though actually ranging from 1.600 to 1.625 in. in diameter (due to metric sizes of the bolts). Although the stress range is the same 100 percent of design live load, the load range had to be increased to account for the increased area of the bolt. All four of these tests (two for each group) ran more than 7,000,000 cycles with no failure. The 7,000,000 loading cycles surpassed the median of the galvanized steel bolts tested during this research by approximately 38 times. The stress range was then increased by 29 percent

TABLE 1
RESULTS OF FATIGUE EVALUATION

	Sample Identification	Sample Type	Sample Diameter, in.	Load Range, lb	Stress Range, psi	Number of Cycles to Failure	Location and Type of Failure
Group 1	A	Galvanized	1-1/2	+34,000 to -13,000	+23,206 to -8,848	41,770	Threads failed
	B	Galvanized	1-1/2	+34,000 to -13,000	+23,206 to -8,848	237,910	Failed last thread before shank
	C	Galvanized	1-1/2	+34,000 to -13,000	+23,206 to -8,848	272,980	Failed last thread before shank
	D	Galvanized	1-1/2	+34,000 to -13,000	+23,206 to -8,848	242,880	Failed last thread before shank
	E	Galvanized	1-1/2	+34,000 to -13,000	+23,206 to -8,848	212,830	Failed last thread before shank
	F	Galvanized	1-1/2	+34,000 to -13,000	+23,206 to -8,848		Failed last thread before shank
	G	Galvanized	1-1/2	+34,000 to -13,000	+23,206 to -8,848	161,320	Failed last thread before shank
	H	Galvanized	1-1/2	+34,000 to -13,000	+23,206 to -8,848	138,740	Failed last thread before shank
	J	Galvanized	1-1/2	+34,000 to -13,000	+23,206 to -8,848	383,490	Failed at last thread to top of top nut
	K	Galvanized	1-1/2	+34,000 to -13,000	+23,206 to -8,848	155,560	Failed last thread before shank
Group 2	L	Plain	1-1/2	+34,000 to -13,000	+23,206 to -8,848	983,800	Failed last thread before shank
	M	Plain	1-1/2	+34,000 to -13,000	+23,206 to -8,848	500	Bolt thread failed in bottom nut
	N	Plain	1-1/2	+34,000 to -13,000	+23,206 to -8,848	627,580	Failed last thread before shank
	P	Plain	1-1/2	+34,000 to -13,000	+23,206 to -8,848	553,710	Failed first thread, top of bottom nut
	R	Plain	1-1/2	+34,000 to -13,000	+23206 to -8,848	307,420	Failed at top of bottom nut
Group 3	C1	Stainless Clad	1.627	+38,500 to -14,700	+23,193 to -8,855	7,001,380	No failure
	C3	Stainless Clad	1.627	+59,400 to -38,000	+35,783 to -22,892	150,360	Failure at upper grip 1st time Failed at 1st thread 2nd time
	C4	Stainless Clad	1.627	+49,700 to -19,000	+29,940 to -11,446	2,919,320	Failed at upper grip twice
	C5	Stainless Clad	1.627	+38,500 to -14,700	+23,193 to -8,855	7,000,000	No failure
	C6	Stainless Clad	1.627	+49,700 to -19,000	+29,940 to -11,446	2,438,800	Failed at upper grip
Group 4	S1	Stainless Solid	1.627	+38,500 to -14,700	+23,193 to -8,855	7,249,320	No failure
	S3	Stainless Solid	1.627	+59,400 to -38,000	+35,783 to -22,892	49,250	Failed at bottom nut 1st thread
	S4	Stainless Solid	1.627	+49,700 to -19,000	+29,940 to -11,446	139,770	Failed at bottom nut 1st thread
	S5	Stainless Solid	1.627	+49,700 to -19,000	+29,940 to -11,446	4,681,540	Failed at bottom nut 1st thread
	S6	Stainless Solid	1.627	+38,500 to -14,700	+23,193 to -8,855	7,000,000	No failure

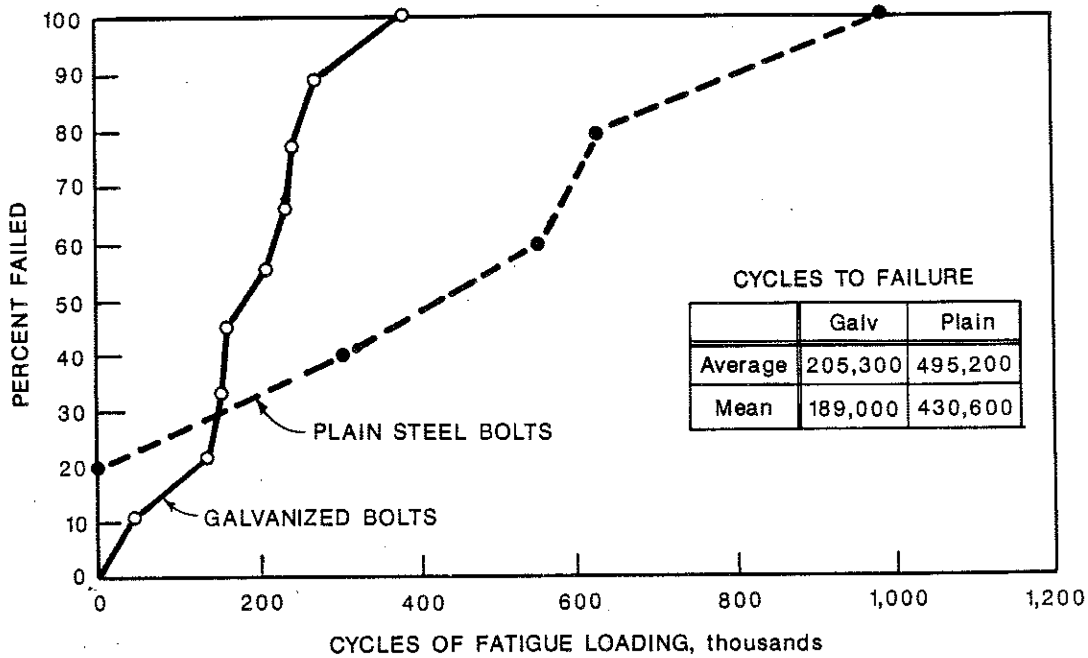

Figure 3. Results of fatigue tests, Group 1 and 2.

over the initial, to try to bring the cycles down to the level of the galvanized bolts. Even at this higher load range the stainless steel clad went an average of approximately 2-1/2 million cycles, 13 times the average of the galvanized bolts. Of the two solid stainless bolts tested at this stress range one went 4.7 million cycles and the other only 140 thousand; no obvious flaw was found to account for this low value. It is not unusual to have a large spread of data points in fatigue life testing, it is unfortunate though that the data set is limited to only two points. With a larger number of specimens a more realistic average or mean could have been calculated.

The stress range was increased again to 83 percent over the initial range. The remaining specimen of each type was tested at this level. The solid stainless steel bolt went 49,250 cycles before failure and the stainless steel clad bolt went 150,360 cycles. Again, the spread of data in a fatigue life experiment can be quite high. One data point is almost insignificant when trying to assess the average or mean fatigue life of a sample. At this level neither the solid stainless nor the stainless clad bolt came up to the mean of the galvanized bolts, although the clad bolt was close. There is no graphical representation of percent failed to cycles of fatigue loading included here, as there was no more than two samples tested at any one range. However, when there is a change in stress ranges it is better to show the relationship between the stress range and the number of cycles. Figure 4 shows the graph of stress vs. cycles to failure for the solid stainless and stainless clad bolts. The relation between the number of load cycles and the stress range is a logarithmic one. In other

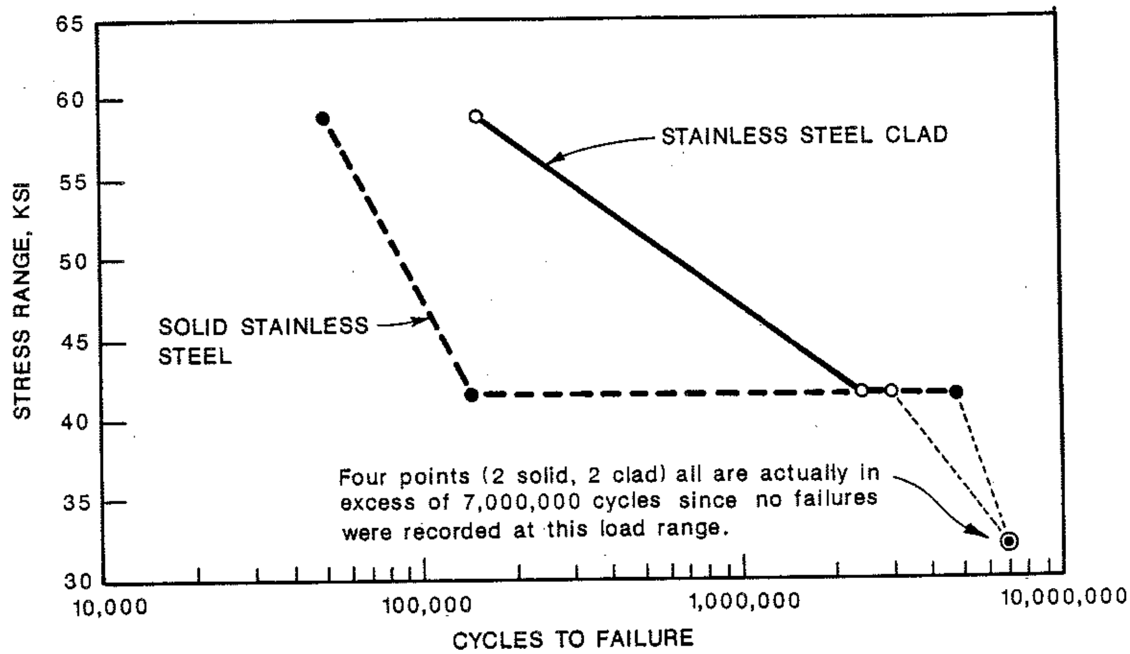

Figure 4. Results of load range changes on fatigue life, Group 3 and 4.

words, even if the load is raised or lowered by only a factor of two (100 percent) the number of cycles can fall or rise by an order of magnitude or more (by raising the stress range by only 83 percent the cycles fell from 7,000,000+ to 49,000).

Mechanical and Chemical Properties - The results of the mechanical property tests are given in Table 2. The Department standard which covers the requirement for these bolts is 8.07.14. All the specimens tested were above the minimum tensile yield strength of 50,000 psi by at least 100 percent, the lowest being 105,000 and the highest being 151,000. The ultimate strength was increased over the required 85,000 psi accordingly, ranging from a low of 128,000 to a high of 183,000 psi. The elongation of the galvanized bolts met the minimum of 12 percent required by the specification, but the plain steel bolts fell short of this requirement averaging out at 10 percent. Both the solid stainless steel and the stainless steel clad bolts met and far exceeded the 12 percent requirement for elongation in spite of their higher tensile strengths. The percent elongation recorded for these bolts was 20 percent. With an elongation of 20 percent these bolts would meet even the new tougher standard of 15 percent now being proposed to AASHTO. The chemical compositions for all bolts used are listed in Table 3.

Closeness of Fit - All bolt nut combinations proved to be within specifications.

TABLE 2
PHYSICAL PROPERTIES OF STEEL USED IN ANCHOR BOLTS

Specimen Identi-fication	Bolt Type	Bolt	Specimen Type**	Yield Point, psi	Ultimate Strength, psi	Percent Elongation	Percent Reduction of Area
E	Galv.	1.500	Reduced	111,400	127,700	12	25
C	Galv.	1.500	Section	110,900	127,700	12	26
J	Galv.	1.500	0.505 in.	110,400	126,400	12	28
L	Plain	1.500	Diameter	128,700	128,700	9*	36
R	Plain	1.500		122,300	129,700	10*	37
N	Plain	1.500		122,900	129,900	11*	37
S6	SS	1.627		151,000	182,700	20	60
S3	SS	1.627		145,800	182,300	19	57
C4***	SS Clad	1.627		105,500	140,500	20	49
C5	SS Clad	1.627	Full Size	123,500	144,200		
C1	SS Clad	1.627		109,700	138,300		

* Below MDOT specifications.
** The full-sized specimens were taken from shank portion of the bolt, and used an 8-in. gage length. The reduced section specimens (0.505 tests) used a 2-in. gage length.
*** Specimen taken from plain steel portion of stainless steel clad anchor bolt.

Note: Specification (8.07.1) requirements are: yield point, 50,000 psi minimum; ultimate strength, 85,000 psi minimum; percent elongation 12 percent minimum.

TABLE 3
CHEMICAL COMPOSITIONS

Element Determined	Percent of Total Composition				
	Steel used in center of clad bolt	Stainless Steel used for cladding	Solid Stainless Steel Bolt	Galvanized Bolt*	Plain Bolt
Carbon	0.32	0.09	0.03	0.33	0.34
Manganese	0.62	1.92	0.67	1.73	1.73
Phosphorous	0.024	0.039	0.023	0.008	0.008
Sulfur	0.048	0.004	0.039	0.27	0.27
Silicon	0.28	0.47	0.36	0.07	0.07
Nickel	2.39	11.05	5.62	<0.02	<0.02
Chrome	0.74	16.73	13.98	0.05	0.05
Molybdenum	0.59	2.33	1.56	0.08	0.07
Copper	0.28	0.33	1.49	0.15	0.11
Titanium	<0.01	<0.01	<0.01	<0.01	<0.01
Selenium	<0.001	<0.001	<0.001	<0.001	<0.001
Tantalum	<0.10	<0.10	<0.10	<0.10	<0.10
Columbium	<0.01	<0.01	<0.01	<0.01	<0.01

*Galvanized bolt metal was analyzed after the galvanizing was chemically removed.

Note: Remainder in all cases is Iron.

DISCUSSION

Galvanized and Plain Anchor Bolts - The results obtained during this experiment tend to reinforce the conclusions reached in the earlier work. Galvanizing the anchor bolts causes a major reduction of their fatigue life. Another area that is related to the fatigue life of the specimen tested is percent elongation. A lower percent elongation is generally an indication of a more brittle material, and may lower fatigue life. In this case the percent elongation for the plain steel and the galvanized bolt are relatively close and there shouldn't be a major lowering of the fatigue life.

The final results for fatigue life of both the plain and galvanized bolts fell between those of the earlier work. The thread root shape was also between the sharp and rounded shapes of the bolts tested earlier. With this in mind it must be concluded that even if the earlier testing fixture induced bending loads into the test they were not at a high enough level to cause any major change in the fatigue life of the bolts tested.

Therefore, it seems reasonable to consolidate the data on plain and galvanized bolts from both experiments into one data base.

Stainless Steel Clad and Solid Stainless Steel Anchor Bolts - The fatigue life of both of these types of bolts at the required 100 percent design load is well beyond what is required from a design standpoint. No failures were recorded even when the four sample bolts (two of each type) were cycled in excess of 7,000,000 times. The load range was then increased to a level that exceeded that used on the 2-in. diameter bolts in the original report (+47,000 to -11,000 lb used for 2-in. bolts in the original report; +49,700 to -19,000 lb used for the second load range for both the stainless steel and stainless steel clad bolts). Here again the average number of cycles to failure exceeds the average for the 2-in. galvanized bolts (the bolts now required by the Department) as well as the 2-in. plain bolts tested in the original report.

The mechanical and chemical properties of these bolts are well within the current specifications, as long as one takes into account the difference in materials (these bolts are not galvanized as required by the specification). The three major factors of the Department's bolt specification 8.07.14; a minimum yield strength of 50,000 psi; a minimum ultimate strength of 85,000 psi; and a minimum elongation at break of 12 percent, are all exceeded by the solid stainless and the stainless steel clad anchor bolts.

There are several differences between the galvanized bolts required by the Department and either of the stainless steel bolts tested. The procedure that is used for applying the threads is different. For the plain and galvanized bolts the threads are generally chased (cut with a die) onto the bolts, and for both the stainless steel and stainless steel clad bolts the threads are rolled. The rolled thread, due to the cold-working action, is 10 to 20 percent stronger than a cut or ground thread and the increase may be much higher when tested in fatigue (2). The rolling process also induces residual compressive stresses into the root of the thread.

When tensile load is applied to the bolt the compressive stresses must first be overcome before the tensile load is transmitted to the material at the root of the thread. Having to first overcome these residual stresses acts as a lowering of the applied tensile load. It is the tensile part of the stress cycle that initiates the cracks that lead to the ultimate failure of the bolt. As can be seen from the original report, when the loads were reduced to 75 percent of design load, the number of cycles to failure increased. The rate of this increase has been shown to be logarithmic. So, even if there are only small levels of residual stresses left by the rolling process, a substantial number of loading cycles will be gained before failure occurs. Another advantage that the rolling process has is that the thread root is rounded. The bottom of the thread has no sharp corners from which cracks can initiate. The shape of the thread root can account for a large increase or decrease in fatigue life as shown in the testing done for the initial report.

One of the reasons that the Department initiated the use of galvanized anchor bolts was their higher resistance to corrosion when compared to the plain steel bolts used before. Stainless steels are affected to a much lesser degree than normal carbon steels by chloride contamination. Although there has been no actual physical investigation done into the corrosion of stainless steels in a chloride environment under this research project, two possible problems have come to the surface as a result of an in-depth literature search.

The first is the possible existence of an oxygen concentration cell. Stainless steels are protected by a passive film (oxide) on their surfaces which essentially makes them an inert metal. In a chloride environment chloride ions attack this film, but if the stainless steel has open access to an oxygen source the film repairs itself. Once this oxygen source is eliminated (such as under the nut) the chloride ion attack may continue and crevices or pits may form. Once this passive layer is breached, the corrosion process continues at rates expected of plain carbon steels. The crevices or pitting that can occur from this type of corrosion cell are the worst possible, in a fatigue type environment. The fatigue life of the bolts could be severely reduced. One way to protect stainless steels from this type of attack is to provide some form of galvanic protection. If a lesser metal is available to act as the anode then the film is preserved and the corrosion process is forestalled. In most cases the sign structure itself will be made of a lesser metal (galvanized steel or aluminum) than the stainless steel anchor bolts, and should provide galvanic protection for these bolts.

Most or all of the research done in this area is directly related to the use of stainless steels in a marine environment. No actual studies were found to have been performed on stainless steels used in a chloride contaminated highway environment. Apparently, until now stainless steel anchor bolts have not been used or tested for use in a highway climate. However, the use of stainless steel nuts and bolts on sign structures is a fairly common occurrence. An examination was made of the condition of these nuts and bolts on several structures along I 96 west of Lansing.

The bolts examined were taken from the base clamps of six different sign structure trusses. These clamping bolts are positioned adjacent to the anchor bolts and are in a similar environment (Fig. 5). Two bolts were taken from the first structure examined (one from the shoulder side and one from the median), all other bolts came from the median base of the five other structures. The bolts were visually examined for corrosion, and all appeared to be in excellent shape. The average time these bolts have been in the field is five years. Measurements were taken at three positions along the thread (close to the shank, the area where the nut was located and close to the end). These dimensions proved to be the same for all three positions (±0.002) for all the bolts sampled. So, it doesn't appear that in this specific instance there will be a problem with the formation of an oxygen concentration cell.

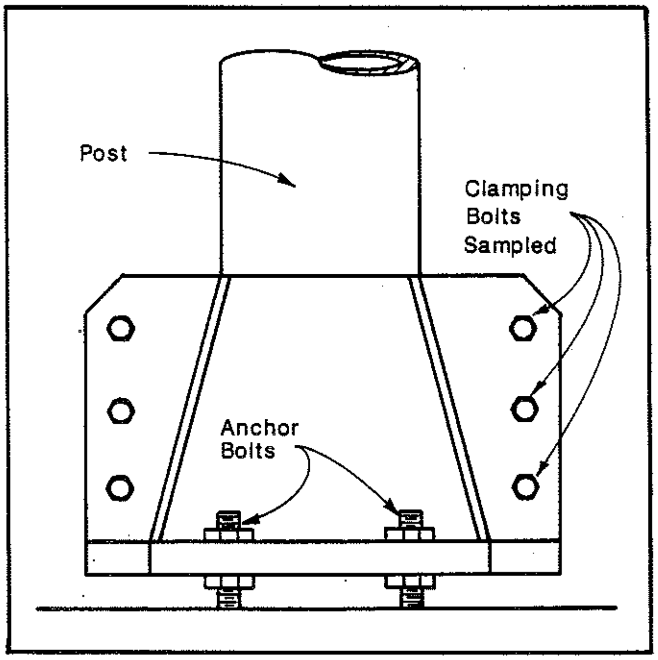

Figure 5. Base of sign structure (truss).

The other problem has to do with the process in which the cladding is attached to the base steel in the clad bolts. "The corrosion resistance of the high alloy stainless steels in acidic chloride environments can be compromised by intermetallic phase precipitation during the hot-roll cladding process" (3). The stainless steel alloy used as cladding on the anchor bolts examined during this investigation fits within the group of alloys examined, and the cladding process used is the hot-rolled system referred to, in the report. This report does its examination on stainless steel bolts subjected to conditions found in flue gas desulfurization, one of the most aggressive environments found in the corrosion industry. The level of acidic chlorides found in a highway environment is insignificant when compared to those found in this industrial setting. This type of corrosion could be found in the anchor bolt environment, but it would probably be at such low levels that no significant reduction in life should be expected.

High Strength of Bolts Tested - A comment should be made about the extremely high tensile strength of the bolts tested, and how that strength relates to the fatigue life of the bolts. It has been proven that as long as the stress field is within the design strength of the weaker specimen, that there will be little or no difference in the fatigue lives of the two. Since the stress fields were calculated using the minimum strength allowed by the specification, there should be no significant change in fatigue life due to the unusually high tensile strength of all the bolts tested. A comparison can even be made between the samples tested in the earlier report and those tested in this work. Both of the groups of bolts from the earlier work were at the minimum yield strength or below. The group of bolts tested in this experiment were at least 100 percent above the minimum. When the fatigue lives of the three groups were compared the group with the highest yield strength actually fell between the other two groups.

Cost Comparison of Stainless Steel vs. Galvanized Bolts

Since the initiation of this investigation an American manufacturer has begun to produce a solid stainless steel bolt that could be used as an anchor bolt. A cost comparison was made between a batch of 2-in. galvanized bolts recently purchased by the Department ($25.03/bolt) and the 1-1/2-in. solid stainless bolts available from the American source ($50/bolt). This cost differential of 100 percent would essentially preclude the use of stainless steel bolts. This would be the case even if it were possible that 1-1/2-in. solid stainless bolts could be substituted for the 2-in. galvanized bolts now used on the larger cantilever sign supports.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Based upon the findings of this investigation the following conclusions were reached:

1) There was reconfirmation that galvanizing reduces the fatigue life of anchor bolts.

2) All anchor bolts tested (galvanized, plain, solid stainless steel, and stainless steel clad) met and exceeded the mechanical requirements of the current MDOT Standard Specification for Construction 8.07.14, with the exception of the elongation at break of the plain steel bolts used.

3) The fatigue life of the galvanized and plain steel bolts fell between the two groups tested in the original report, indicating that no significant bending loads were introduced by the testing fixture used in the original experiment.

4) The average fatigue life of the solid stainless steel and stainless steel clad bolts exceeded that of the galvanized bolts (presently required by the Department) by more than an order of magnitude. Although only limited testing was done, when the stainless steel bolts were subjected to a higher load, their average fatigue life exceeded the fatigue life of the 2-in. diameter bolts tested in the original report (1). It is possible that the 1-5/8-in. diameter stainless steel bolts could be substituted for the 2-in. diameter bolts now in use.

5) The use of stainless steel bolts is not cost competitive even if smaller diameter stainless steel bolts could be substituted for the 2-in. galvanized bolts.

Recommendations

We cannot recommend the inclusion of stainless steel bolts as an alternate to the galvanized bolts now in use by the Department, due to the large cost differential. Nor would we recommend any further study to see if the 1-5/8-in. stainless steel bolts could be substituted for the 2-in. galvanized bolts due to their higher fatigue strength. The 1-1/2-in. stainless steel bolts cost 100 percent more than the 2-in. galvanized ones. If there is a very severe environment where the presently specified galvanized anchor bolts show poor durability, stainless or stainless clad bolts should be considered for solving the problem.

No other work can be done on this project due to other higher priority work. This final report will be used to close the project.

REFERENCES

1. Arnold, C. J., Johnson, D. F., and Chiunti, M. A., "Static and Dynamic Properties of Anchor Bolts for Sign Supports," Research Project 77 F-153, Research Report No. R-1197, Materials & Technology Division, Michigan Department of Transportation, June 1982.

2. Oberg, Eric, Jones, Franklin D., and Horton, Holbrook L., "Machinery's Handbook," 22nd Revised Edition, Industrial Press, Inc., New York, 1984, pp. 1455.

3. Lindsey, P.B., "Effect of Heat Treatment on the Corrosion Resistance of High-Alloy Stainless Steel and Nickel-Base Alloys," Presented during Corrosion/86, Paper No. 187, NACE, Houston, Texas, 1986.

APPENDIX

Michigan Department of Transportation, Standard Specifications for Construction, 1984 Edition.

8.07.14 Anchor Bolts, Nuts, and Washers.-All nuts, washers, and the exposed length of anchor bolts plus 3 inches shall be galvanized in conformance with ASTM A 153, Class C. Nuts shall be retapped after galvanizing in accordance with ASTM A 563.

Anchor bolts for sign supports and light standards shall be of the dimensions shown on the plans and shall be fabricated from medium carbon, hot rolled steel bars with a minimum yield strength of 50,000 psi, a minimum tensile strength of 85,000 psi, and at least 12 percent elongation in a 2-inch gage length. Nuts for these bolts shall be Galvanized, Heavy Hexagon Series, meeting the requirements for carbon steel nuts of ASTM A 563, Grade A or stronger.

Anchor bolts and nuts for other purposes shall be fabricated from steel meeting the requirements of ASTM A 307. Nuts shall be Heavy Hexagon Series.