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16. ABSTRACT
This paper gives some background for the recent changes made in the Specifications for Structural Joints Using ASTM A325 or A490 Bolts published in March 1970 by the Research Council on Riveted and Bolted Structural Joints that allow the use of certain coatings on the faying surfaces of friction-type joints.

More recent tests by the Jet Propulsion Laboratory at California Institute of Technology on faying surfaces coated with inorganic zinc silicate paints are compared to those of the Universities of Illinois and Washington. It is concluded that the acceptability of coatings should not be limited to the coefficient of friction but be based on the slippage characteristics of the joints at load levels below the point of major slip. Recommendations are made to continue the ban on the coating of faying surfaces and to conduct tests on bolted joints using certain primers being used at present.

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September 1971
Final Report
M&R No. 762504-646610

Mr. John L. Beaton
Materials and Research Engineer

Dear Sir:

Submitted for your consideration is a report of:

A LITERATURE SEARCH ON THE

EFFECT OF COATINGS ON FAYING SURFACES OF

HIGH STRENGTH BOLTED JOINTS

Study made by . . . . Structural Materials Section
Under Direction of . . . . E. F. Nordlin
Work Supervised by . . . . J. R. Stoker
Project Engineer . . . . David Hopkins
Report Prepared by . . . . David Hopkins

Very truly yours,

Eric F. Nordlin

Eric F. Nordlin
Assistant Materials and Research
Engineer - Structural

DH:mw

Attachment

cc: ALElliott

71-39

ABSTRACT

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More recent tests by the Jet Propulsion Laboratory at California Institute of Technology on faying surfaces coated with inorganic zinc silicate paints are compared to those of the Universities of Illinois and Washington. It is concluded that the acceptability of coatings should not be limited to the coefficient of friction but be based on the slippage characteristics of the joints at load levels below the point of major slip. Recommendations are made to continue the ban on the coating of faying surfaces and to conduct tests on bolted joints using certain primers being used at present.

KEY WORDS: bolted joints, faying surfaces, high strength bolts, protective coatings, slippage.

INTRODUCTION

For a number of years maintenance personnel have reported that the faying surfaces of some connections on structural steel bridges are corroded. In some instances separation of the plates and elongation of the fasteners have resulted while in other cases unsightly rust stains have appeared on the surfaces of the supporting concrete abutments and piers.

While no actual survey has been made, it is estimated by the bridge maintenance personnel that this situation exists on some fifty bridges in the state. It has been observed to be more common on older truss type bridges than on newer plate girder types. The connections on trusses are more exposed to the elements than the diaphragm connections of the plate girder type of construction.

Efforts have been made in the field to seal these joints from water penetration but a more positive solution has been recommended, namely, the use of protective coatings on the faying surfaces before assembly. In addition to providing corrosion protection, coating would make it unnecessary to mask off connection areas during the shop coating and would reduce the amount of field sandblasting and priming of the connection areas after assembly.

The objective of this research project was to determine if the primers for structural steel presently being used, or being considered for use in the future, have satisfactory slippage characteristics when used on the faying surfaces of high strength bolted joints. Of primary interest was the use of zinc based type paint systems. All available literature on the effect of protective coatings on faying surfaces of bolted joints was reviewed and analyzed. Specifications of other states, agencies, and associations were also reviewed to see what the current practice is in this field.

Authority to proceed with this project was given by John L. Beaton, Materials and Research Engineer, on July 20, 1971. This was a State financed research project.

BACKGROUND

The early interest in bolted joints was the result of tests that showed better fatigue life over riveted joints. This was due to the friction character of bolted joints. Riveted joints that rely on bearing of the rivets on the hole sides have lower fatigue life due to the resulting stress concentrations[25].

The first specifications issued in 1951 by the Research Council on Riveted and Bolted Structural Joints (RCRBSJ) stated, "Faying surfaces, when assembled, shall be bare, either descaled or carrying normal mill scale. Faying surfaces shall be free of paint, lacquer, dirt, oil, loose scale, burrs, pits, and other defects that would prevent solid seating of the parts or would interfere with the development of friction between the parts[6]". Tests made on joints with red lead paint on the faying surfaces slipped at much lower loads than the same joints with plain mill scale[13].

In the succeeding specifications by RCRBSJ, a distinction was made between those joints where slippage of the parts with the bolts coming into contact with the sides of holes was not detrimental and those joints where it was not acceptable. The former became known as "bearing-type" joints and the latter became known as "friction-type" joints. The friction type was defined as a shear connection subjected to stress reversal, severe stress fluctuation, impact or vibration, or where slippage would be undesirable. Bearing type joints were permitted to have a shop coat of paint on the faying surface. Friction type joints continued to have a ban on coatings[5]. California Division of Highways bridge designers have used the allowable stresses designated for friction-type joints for all connections.

Later tests showed that the relation of load to slip of a joint was greatly affected by the axial tension of the bolts[23], and it was later established that an efficient and economical joint had to have bolts with high initial tension[24,23].

A typical static test of a bolted joint with mill scale faying showed very little slippage until a load was eventually reached at which the initial frictional resistance to slip was overcome, and the plates slipped with extreme rapidity. This came to be known as the point of major slip[13] (see Figure 1). Researchers began taking the load that corresponded to that load and dividing it by the total clamping force exerted by the bolts. They called the result the coefficient of friction or coefficient of slip.

In 1960 the Research Council decided to use 0.35 for the coefficient of friction for mill scale surfaces. Tests had shown lower values generally, but the Council felt their value was more typical of field conditions. They also came up with a formula for safety factor against major slip:

$$N = \frac{0.35 \text{ X bolt tension}}{\text{allowable shear stress X nominal bolt shear area}}$$

It can be shown that this coefficient of friction gives a safety factor, N, of 1.5 to 1.7 for A325 and A490 bolts. However, allowable overstressing permitted by the codes can reduce or overcome this margin of safety and designers of "friction-type" joints were cautioned to so proportion these joints as to satisfy themselves that the margin was adequate.

In the ten years since these specifications were published, many tests have been made using different coatings on the faying surfaces such as hot dip galvanizing, hot-zinc sprayed coating known as metallized zinc, zinc rich inorganic silicate paints, vinyl wash and linseed oil. The most promising of these coatings were hot dip galvanizing, inorganic zinc paint and metallized zinc applied to grit blasted surface. When the surface of hot dip galvanized steel is lightly blasted, a mean coefficient of friction of 0.49 was obtained. Inorganic zinc gave a coefficient of 0.51 and metallized zinc 0.65. Table 1 summarizes the result of some tests performed during the last fifteen years. These favorable test results were the basis for the 1970 Research Council specifications which allow the coating of the faying surface of friction type joint with the following:

1. Hot dipped galvanizing if contact surfaces are scored by wire brushing or light blasting after galvanizing and prior to assembly.

2. Inorganic zinc silicate paint (on blasted surfaces for best results).

3. Metallized zinc or aluminum on blasted surfaces.

In the meantime results of a series of tests by the Jet Propulsion Laboratory at California Institute of Technology have been published which cast doubt on the use of inorganic zinc silicate paint as a coating for faying surfaces. The conductors of these tests contend that the paint breaks down under the pressure of the bolts and the reversal of load causing the bolts to lose their preload leading to excessive slippage[16,17].

DISCUSSION

Zinc Rich Paint

A limited number of research projects have been published in this country where faying surfaces have been coated with inorganic zinc silicate paint. A summary of these tests is shown in Table 2. No tests have been published where organic zinc or basic lead silico chromate paint have been used on the faying surfaces. These three paints are presently the principal primers being considered by the Division of Highways for structural steel high tensile bolted joints.

An inspection of Table 2 will reveal that the tests run by Munse and Brookhart were concerned with determining the coefficient of friction that resulted from using inorganic zinc silicate paint on the faying surfaces. Munse also investigated the fatigue strength of the connections. The fatigue test performed by Munse was of such rapid speed, 180 cpm, that slippage was limited to the instanteous reaction. The grips were 2" to 2-5/16" and the bolt tension varied from 40 to 46.5 kips. A325 bolts were used for all tests by Munse and Brookhart.

The tests sponsored by the Jet Propulsion Laboratory were a departure from previous tests. Static reversal tests were carried out by subjecting the joints to a tension load for one hour followed by a compression load for one hour. Five complete cycles were performed for a total of ten hours. Slippage of the joints was measured and bolt tension was also measured before and after the tests. Joints bolted with A325 bolts showed tolerable slippage (0.001") at shear stress levels of 143% allowable for friction-type bridge joints. Joints bolted with A490 bolts showed significant slippage (0.009") at shear stress levels of 155% allowable. This is about 50% greater slippage than results of tests with plain mill scale surfaces and A490 bolts.

The authors of these tests attribute the difference in the behavior of the two bolt types to the following:

> "A490 bolts have 20% greater bolt clamping pressure than A325 bolts, and this apparently causes premature microscopic physical breakdown of the inorganic zinc coating; and this breakdown, in combination with the abrading action of the stress reversals results in a loss of bolt elongation and, hence, a loss in original bolt clamping pressure, and consequently increased slip displacement[8]."

The bolt grips of the Jet Propulsion Laboratory test specimens were 3/4 to 7/8 in., including washers, which is much smaller than the 2 to 2-5/16 in. of the Munse and Brookhart series. Consequently, any compression or loss of paint thickness of the JPL specimens would result in a much larger loss of bolt tension. It is reasonable to expect more slippage to result as bolt tension is reduced. At present the majority of bolted joints being used in bridge construction have grips in the range of 1 to 1-1/8 inches.

The bolts in the JPL tests were torqued to a value calibrated to give a bolt tension equal to the proof load plus not more than 10%. In actual practice bolts are tensioned by several methods. One of the most popular is the "turn of the nut" method. For bolt lengths under 8", nuts are tightened by hand wrench to snug tight, then given 1/2 a turn to a complete tensioning. Figure 2 indicates the results of using this "turn of the nut" method on a particular lot of bolts with grips of 1-9/32 inches. This gives bolt tensions far greater than the minimum required, approximately 50% more for A325 and A490 bolts. It is reasonable to expect that A325 bolts of short grips, in the neighborhood of 1 inch, tightened by the turn of the nut method, will give bolt clamping forces as high as the A490 bolts used in the JPL series of tests. Consequently, it can be argued that if the reasons given by the JPL authors are correct for the adverse slippage behavior of the A490 bolted joints, then the same results can be expected in the field for A325 bolted joints where "turn of the nut" tightening is used.

Painting of bridges and signs in California has been divided into zones. Along the coast where exposure is the most severe, inorganic zinc silicate primers and organic zinc primers with vinyl top coats are presently being used. Inland, bridges are presently coated with basic lead silico chromate primers.

It is anticipated in the future more bridges will be painted with zinc rich paints because of their good service history. They outlive other systems by a substantial amount. Bridges where painting presents site difficulties, such as overcrossings over busy freeways, will probably be painted with zinc paints in the future even though they are inland locations.

Another factor affecting the future of painting of bridges and signs is the public attitudes toward the dust from sandblasting and the toxic ingredients of some paints. In the Los Angeles area a ban is being considered on open sandblasting. These factors favor nontoxic paint systems with longer service lives over initially less costly systems. Zinc rich paint systems meet these requirements.

At present zinc rich paints with organic vehicles are being tested and used for bridges and sign structures. This paint appears to offer two advantages over the two component inorganic zinc silicate paints. Firstly, it can be manufactured and delivered to the jobsite as one component in one container. No field mixing of components is necessary, and secondly it appears to bond better to the parent metal.

Galvanized Steel

The galvanizing of steel structures at present is largely limited to sign structures on the California highway system. All steel sign structures except the box beam type are called out to be galvanized after complete or partial fabrication. And the coating of the faying surfaces of high strength bolted joints with galvanizing or paint is permitted on sign structures.

In recent years a number of small county bridges of galvanized steel have been built on secondary roads in the United States, and, in Canada, the well known Lizzoth Bridge, a deck arch truss type, has been opened to traffic. In California galvanizing steel bridge members has not been given serious consideration due to the limited size of the galvanizing tanks available.

Tests of bolted joints with faying surfaces coated with galvanizing have shown a low resistance to slippage. Tests where the joint was subjected to stress reversal have shown a phenomena of decreasing slippage with increase of cycles which approaches the slippage of mill scale surfaces. This is known as "lock up" and results from the cold welding of the zinc surfaces (see Figure 3).

Tests by the University of Illinois[8,9] of bolted joints where the galvanized faying surfaces were scored with a wire brush or lightly blasted with sand have shown a high coefficient of friction. While no data was published on the joint deformation, it was indicated that no slippage occurred on some of these joints at high bolt shear stresses.

Summary - Policy of Other States, Agencies, Associations

A review of the standard specifications for the following states and agencies was conducted during this study:

Arizona 1969	New Hampshire 1969
Connecticut 1969	Ohio 1967
Georgia 1966	Oregon 1970
Idaho 1971	Tennessee 1968
Illinois 1968	Texas 1962
Indiana 1970	Washington 1969
Maryland 1969	Bureau of Public Roads 1969
Massachusetts 1967	AREA 1970
Missouri 1968	AISC 1970
Steel Structures Painting Council 1969	

In addition the special provisions for the following were reviewed:

Bureau of Reclamation - Auburn Foresthill Bridge Superstructure 1970
Washington State - White Salmon River Bridge 1970

With only two exceptions, specifications and manuals reviewed banned the use of paint on the contact surfaces of friction-type joints. One exception was Illinois which allows paint on secondary members. Most of the states reviewed followed the wording of AASHO which states, "Contact surfaces of friction-type joints shall be free of oil, paint, lacquer, rust inhibitor or galvanizing". The other exception to this ban was the special provisions of Washington State's White Salmon River Bridge which states, "The contact surfaces of bolted joints shall be painted with only the shop coat of inorganic zinc silicate paint (2.5 mils min.)."

In addition to the above exceptions, the Division of Bay Toll Crossing of the State of California informally permitted the contractor on the San Diego-Coronado Bridge to "mist coat" the contact areas of the bolted joints with 1 to 1½ mils of inorganic zinc silicate before assembly. The contact areas were sandblasted prior to painting.

CONCLUSIONS

The complete reliance on the coefficient of friction to judge the acceptability of coatings on faying surfaces for friction-type bolted connections is not justified. The JPL tests on inorganic zinc silicate paint established that significant slip can occur at loads short of the point of major slip. These slippages are large enough to reduce or limit the load in a member significantly with an accompanying redistribution of load to other members of the structure. Additionally the loss of some tension in the bolts due to compression of the coating and abrasion of the paint could lead to lower fatigue life of the connection by dropping the point of major slip to the working range.

RECOMMENDATIONS

As a result of this literature search, it is recommended that the ban on the coating of faying surfaces with any of the paints presently being used on steel structures by the Division of Highways be continued.

It is also recommended that a series of tests be conducted on bolted joints which have faying surfaces coated with the primers presently being used by the Division of Highways.

The following table lists the parameters recommended:

Coatings: Mill scale

Mill scale		
Sandblasted		
Galvanizing	2 oz./sq. ft.	
Inorganic zinc silicate	701-80-56	2½ to 3 mils
Organic zinc	701-80-62	2½ to 3 mils
Basic lead silico chromate	701-80-83	1½ mils

Painted specimens are to be sandblasted to white metal prior to painting.

Galvanized faying surfaces are to be lightly sandblasted before assembly.

Test Specimens: Angle and plate combinations, single shear grip approximately 1 inch, 4 bolts per connection.

Bolts: A325 7/8 Ø

A490 7/8 Ø

Bolt Tension: Proof load, and snug plus 1/2 turn.

Loading: Sufficient to produce bolt shear stresses of 100 and 150% of allowable for friction type joints.

Test Method: Reverse Static

1/2 hour compression and 1/2 hour tension

100 cycles

Data to be collected:

1. Joint slippage.

2. Bolt tension - before and after test.

3. Joint load.

4. Coating thickness.

5. Tensile load and elongation relation of bolts.

6. Coating hardness (pencil test).

7. Coating abrasive resistance (Taber Abraser).

A correlation between the hardness and abrasive resistance of coatings and their behavior on the faying surface of a bolted joint is desirable as a way of evaluating the acceptability of a proposed protective coating.

The loading of the joints to 150% of the allowable shear stress is to insure that joints in practice will have sufficient safety factor against significant slip at overloads and allowable overstress permitted by the design specifications.

Surface Treatment		No. of Tests	Slip Coefficient		
			Mean	Min.	Max.
I.	Plain Steel				
(a)	Mill scale	352	0.32	0.17	0.60
(b)	Rusted	15	0.43	0.41	0.55
(c)	Flame cleaned	88	0.48	0.31	0.75
(d)	Blast cleaned	183	0.57	0.32	0.81
II.	Steel with Corrosion Protection				
(a)	Red Lead Paint	6	0.07	0.05	
(b)	Rust Preventative Paint	3	0.11	0.07	
(c)	Hot-dip galvanized	95	0.19	0.08	0.36
(d)	Lacquer - varnish	17	0.24	0.10	0.30
(e)	Blast cleaned - vinyl wash	24	0.28	0.22	0.34
(f)	Galvanized & grit blasted	12	0.49	0.42	0.55
(g)	Grit blasted & zinc rich paint	48	0.51	0.38	0.65
(h)	Grit blasted & metallized	42	0.65	0.42	0.99

TABLE NO. 1 (18)

TABLE 2

INORGANIC ZINC SILICATE TESTS

Author Date	Coating	Test Method	Bolt Type	Single Shear Stress Ksi	Slip In.	Coef. Friction Kips	Bolt Tension Kips	Grip* No. Specimen
Munse 1961 [23]	Dimetcote #3	Static Fatigue 180 cpm	A325 7/8" dia.	8.7 - to + 13.0 0 to -	.001" max.	.47	46.5	2 5/16" 2 static 2 fatigue
Munse 1967 [22]	Rust Ban 191 3.3 mils	Static Fatigue 180 cpm	A325 7/8" dia.	8.7 - to + 13.0 o to -	NR	.59	46	2" 2 static 2 fatigue
Munse 1968 [21]	Dimetcote #5 and #6	Static Fatigue 180 cpm	A325 7/8" dia.	8.7 - to + 13.0 0 to -	NR	.47 .52	40-42	2" 2 static 2 fatigue
Brookhart 1966-68 [10]	Rust Ban	Static	A325 1" dia.		NR	.60	43.6 & 21.8	2¼" 3 static
JPL Phase I 1968 [17]	Dimetcote #3 .4 to 1 mil	Static Reversal 2 cp hour, Total 5	A325 A490 3/4" dia.	14.6 21.4	.0128 .1661	- -	29-31 40-44	3/4" 7/8" 1 each bolt type
JPL Phase II [18]	Dimetcote #3 4 mils	Static Reversal 1 cp hour Total 5	A325 3/4" dia.	11.0 13.9 19.3	.0008 .0009 .0010		28-31	3/4"
			A490 3/4" dia.	12.1 20.1 28.1	.0014 .0028 .0086		40-44	7/8" 3 tests/ stress

*Includes washers

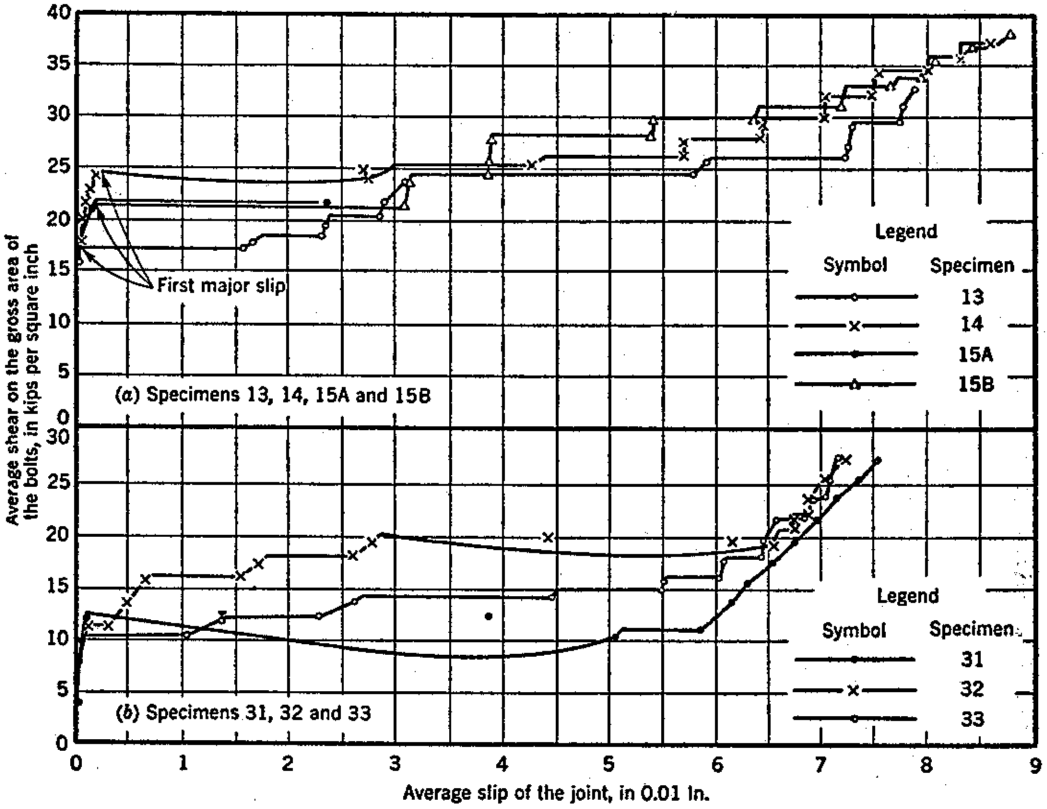

FIGURE 1

COMPARISON OF NOMINAL SHEAR ON THE BOLTS AND AVERAGE SLIP OF THE JOINTS (13). CONTACT SURFACES OF JOINTS IN (a) AND (b) WERE BARE STEEL WITH MILL SCALE. BOLT TENSION OF JOINTS IN (b) WERE APPROXIMATELY ONE HALF THAT OF BOLTS IN (a).

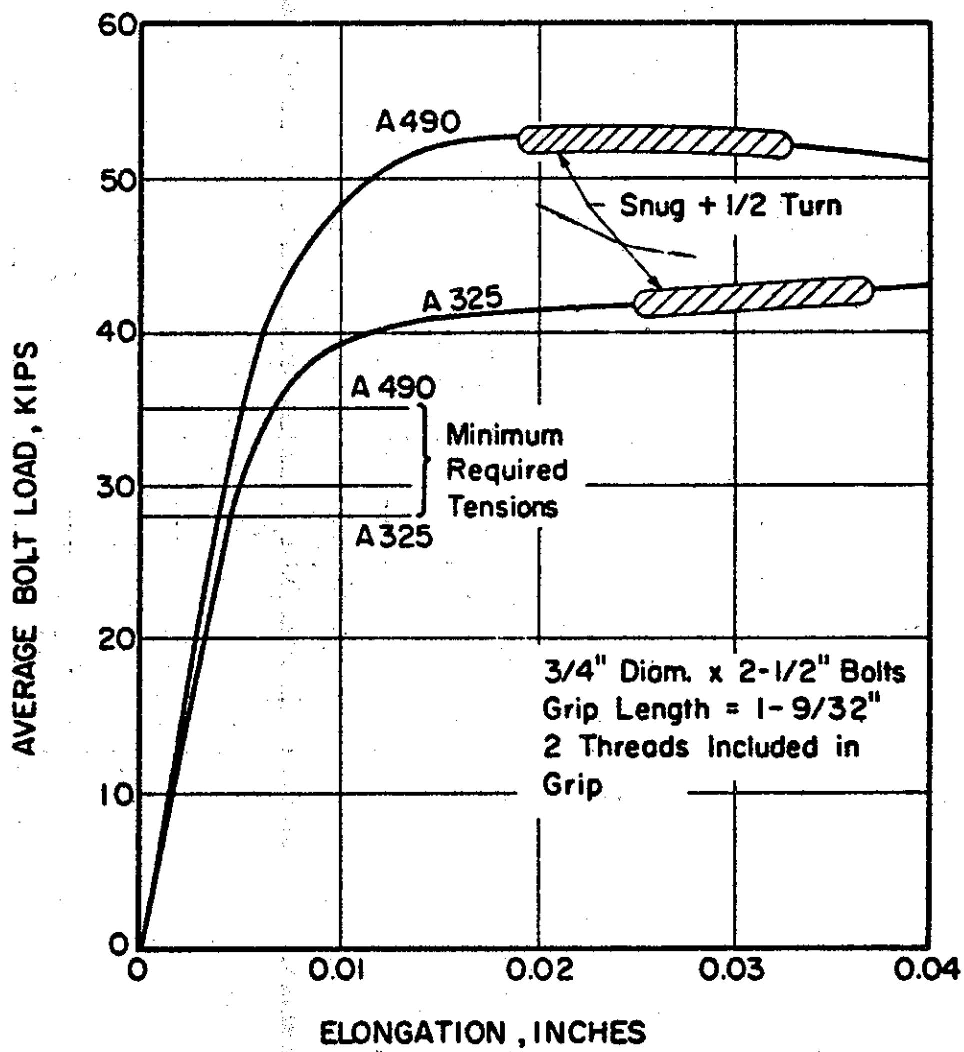

FIGURE 2

LOAD-ELONGATION BEHAVIOR FOR HIGH-STRENGTH BOLTS IN TORQUED TENSION (7).

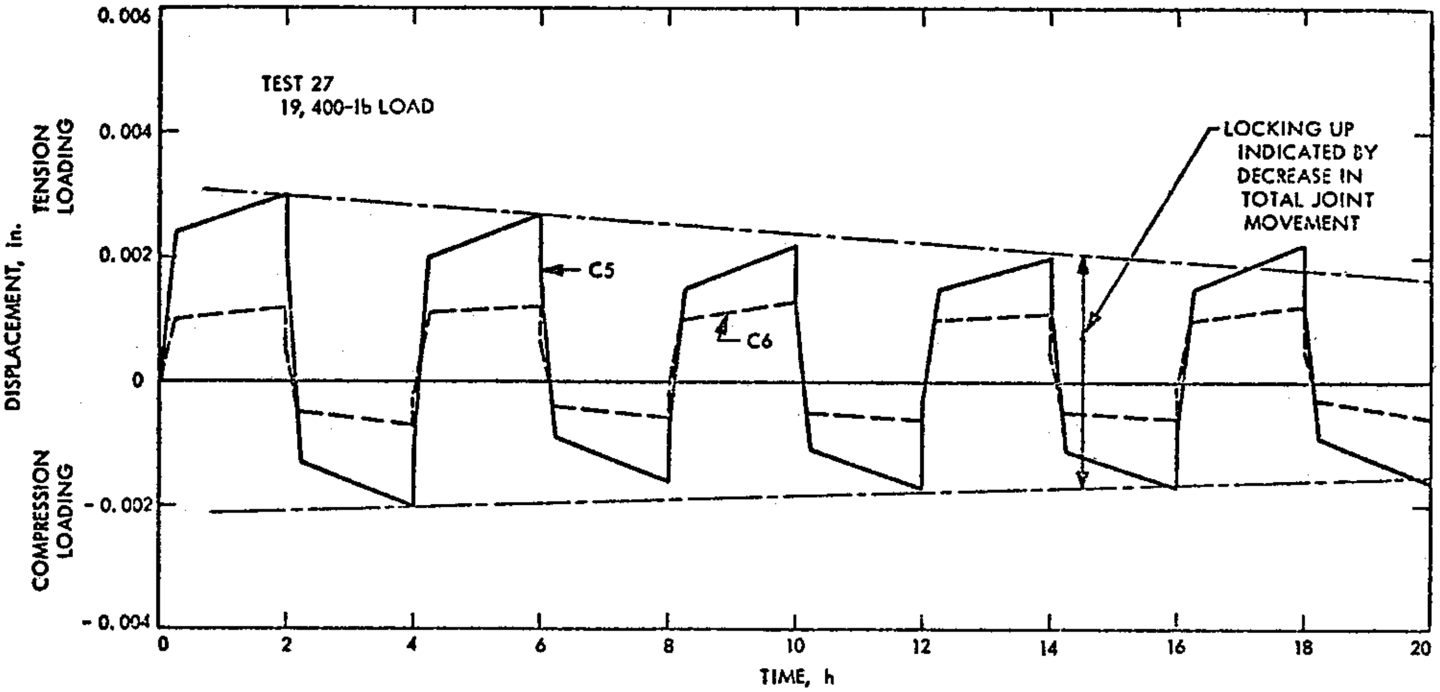

FIGURE 3

DEFLECTION TIME GRAPH FOR HOT-DIP GALVANIZED FAYING SURFACE[18].

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