Effect of Overspray and Incomplete Masking of Faying Surfaces on the Slip Resistance of Bolted Connections

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Despite precautions taken to protect contact areas during painting, some overspray from painting of surfaces adjacent to faying surfaces may take place. Although current specifications[1] permit the use of certain coatings, such as hot-dip galvanizing, inorganic zinc-rich paints and metallized zinc or aluminum on the surfaces of friction connections, the paint used on the remainder of the structure could be of the type which is not acceptable for use on faying surfaces. The effect of this inadvertent coating of the faying surfaces is not known. It has been suggested[2] that the degree to which overspray affects the slip performance of friction-type connections depends on the average overspray paint film thickness, regardless of the type of paint used. Overspray, however, is not a true paint coating and is, therefore, very difficult to establish a film thickness, as suggested by Ref. 2.

This paper deals with the results of an experimental project sponsored by the American Institute of Steel Construction and the Research Council on Structural Connections (RCSC) carried out at the University of Texas-Austin to study the effect of overspray on the faying surfaces of friction-type connections. More specifically, the objectives of this project are to determine the slip performance of friction-type connections under the influence of: (a) overspray on the faying surfaces, and (b) incomplete masking of the faying surfaces.

The experimental project involved the testing of 65 specimens consisting of three identical plates arranged as shown in Fig. 1.

The parametric variations considered in this investigation involved the surface conditions of the connected parts and the masking pattern. Both mill scale and sandblasted surfaces were considered. To evaluate the influence of incomplete masking of the faying surfaces, two masking patterns were used: a 2-in. square masking around the hole and a 2-in. vertical strip symmetrical about the hole, as in Fig. 2.

A recent study at The University of Texas-Austin[3] showed certain types of paint enhance the slip performance of friction-type connections. It was shown in the study that in some cases the slip coefficients of painted connections were greater than or equal to the slip coefficients of unpainted connections. Thus, it was assumed overspray conditions resulting from such superior paints could not result in slip coefficients lower than those corresponding to paint-free conditions. Therefore, no such paints were considered in the present investigation. Instead, the decision was made to try a single paint product, one which would be detrimental to the slip resistance of the joint. Thus, a red oxide primer (50% solids) used by a local fabricator was chosen. Since this paint produced slip coefficients which were lower than those of unpainted mill scale and blasted surfaces, it was used throughout the project.

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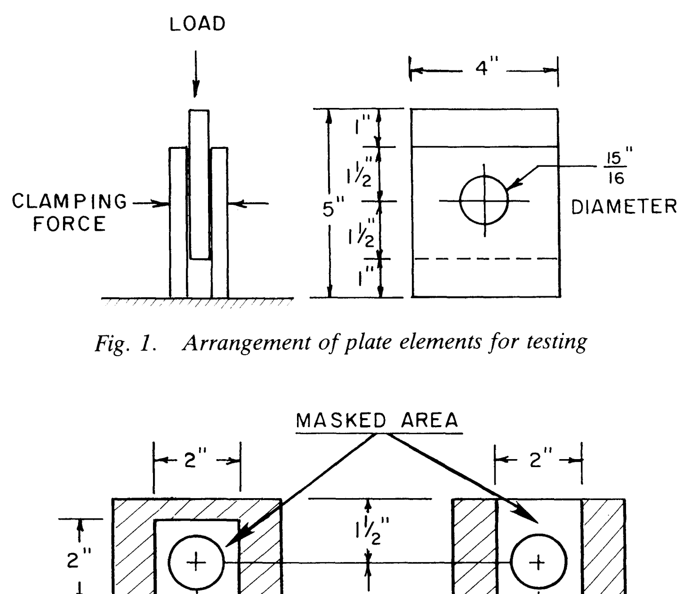


Fig. 1. Arrangement of plate elements for testing

Fig. 2. Masking patterns

Table 1. Average Slip Coefficients[a]

Tested Surface Conditions	Surface Condition Prior to Painting: Clean Mill Scale t = 3/8 in.	Clean Mill Scale t = 3/4 in.	Sand-blasted t = 3/8 in.
Paint-free	0.31[b] (4)	0.32[b] (5)	0.58[c] (3)
Painted, with a 2-in. sq. mask	0.24 (5)	——	——
Painted, with a 2-in. strip mask	0.25 (5)	0.19 (4)	0.40 (4)
Totally painted	0.17 (5)	0.15 (9)	0.18 (4)
Over-sprayed			
Heavy	0.17 (5)	0.17 (4)	0.29 (4)
Light	——	0.19 (4)	——

[a]Numbers in parentheses indicated number of specimens tests.
[b]Average slip coefficient = 0.33, according to Fisher and Struik.
[c]Average slip coefficient = 0.47, according to Fisher and Struik.

Although the majority of the steel plates used in this investigation were 3/8-in. thick, some tests were carried out using 3/4-in. thick plates. All specimens were A36 steel. In total, 65 specimens were tested with the surface conditions listed in Table 1.

PREPARATION OF SPECIMENS

The specimens consisted of identical plates 4-in. × 4-in. with a 15/16-in. dia. hole, shown in Fig. 1. The steel was donated by the Mosher Steel Company in the form of either 4-in. × 4-in. plates with punched holes or plate strips of the same steel quality as the 4-in. × 4-in. plates. These plates were cut to required size and holes drilled at the laboratory. After testing the various painting conditions, the plates were sand-blasted commercially using No. 6 sand and recoated.

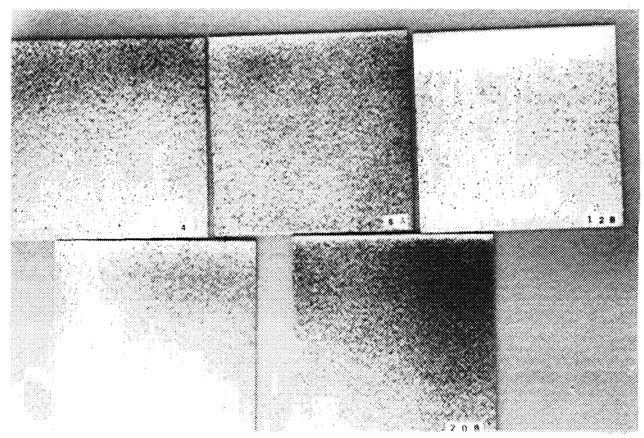
Painting and spraying of the specimens was done at the laboratory using a spray gun and a pressure cup. The dry paint thickness, measured with a magnetic gage, ranged from 1.5 to 4.4 mils, with an average value of 2.3 mils on the painted surfaces of those specimens used in the masking experiments.

The same type of paint was used for the over-sprayed specimens. Since an overspray condition is not a true paint coating but simply a random scatter of paint droplets of varying degrees of consistency and thickness, this condition could not be measured directly. To obtain a visual record of the over-spray, cold-formed plates painted white were positioned at regular intervals between plates to be over-sprayed (typical interval = 3 plates). The white paint provided an effective background for evaluating the degree of over-spray. Upon applying the over-spray coatings to the plates, the white plates received over-spray conditions equivalent to those plates in the immediate vicinity. Photographs documented the over-spray conditions, and these were used as reference standards.

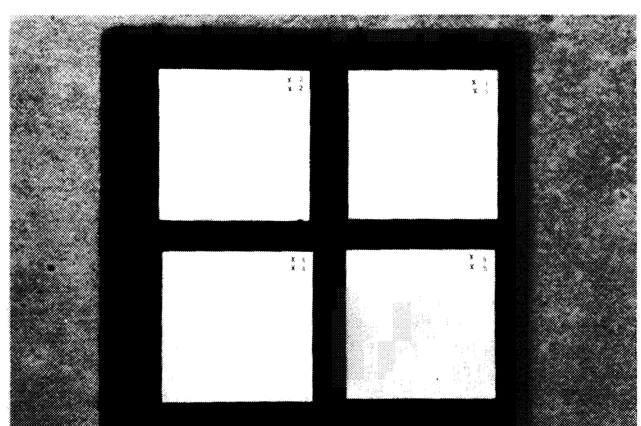
In this experimental project two sets of specimens were tested. The first set was subjected to a higher degree of over-spray than the second set. To distinguish between the two sets, the first set is labelled "heavy" and the second "light." Typical reference plates for the two over-spray conditions are shown in Fig. 3.

TESTING PROCEDURE

The test procedure used in this investigation was developed at The University of Texas to test shear connections with painted contact surfaces.[4] This method has been adopted by RCSC for testing the slip resistance of coated



a) Heavy overspray



b) Light overspray

Fig. 3. Over-sprayed reference plates

surfaces. This setup required identical plates with the same hole pattern to be arranged in a symmetric fashion and the shear load applied directly to the specimen. This arrangement is shown in Fig. 1.

The desired clamping force was applied by a high-strength steel rod, ⅞-in. in dia., acting with a center-hole hydraulic jack. The clamping force was 39 kips, the minimum specified for a ⅞-in. A325 bolt. The test setup permitted the same clamping force to be developed in all test specimens, thus reducing the test scatter which is usually present when actual bolts provide the clamping force.

Two direct current displacement transducers (DCDT's) were used to measure the relative movement between the middle specimen plate and the base plate. The output from the hydraulic testing machine and the DCDT's was automatically plotted by an X-Y plotter.

A strain indicator monitored the clamping force in the bolt which was continuously maintained at the required value of 39 kips. The test was terminated when the hydraulic bolt went into bearing or when there was a large decrease in the applied shear load.

TEST RESULTS AND DISCUSSION

The discussion on the slip performance characteristics of the connections tested was based on the experimental slip coefficient determined from the following relationship:

$$\text{slip coefficient} = \frac{\text{slip load}}{\text{clamping force} \times \text{number of slip planes}}$$

The slip load was determined from the load-deflection plots and consisted of either: the maximum load achieved before the plates went into bearing with the bolt, or the load at which a sudden increase in deflection took place.

The average slip coefficients for each surface condition examined are given in Table 2. A graphical representation of all slip coefficients is in Figs. 4 and 5.

The following discussion of the results focuses on how: (1) full paint coating on faying surfaces; (2) over-spray on faying surfaces; and (3) incomplete masking of faying surfaces affect the slip performance of the friction-type connections.

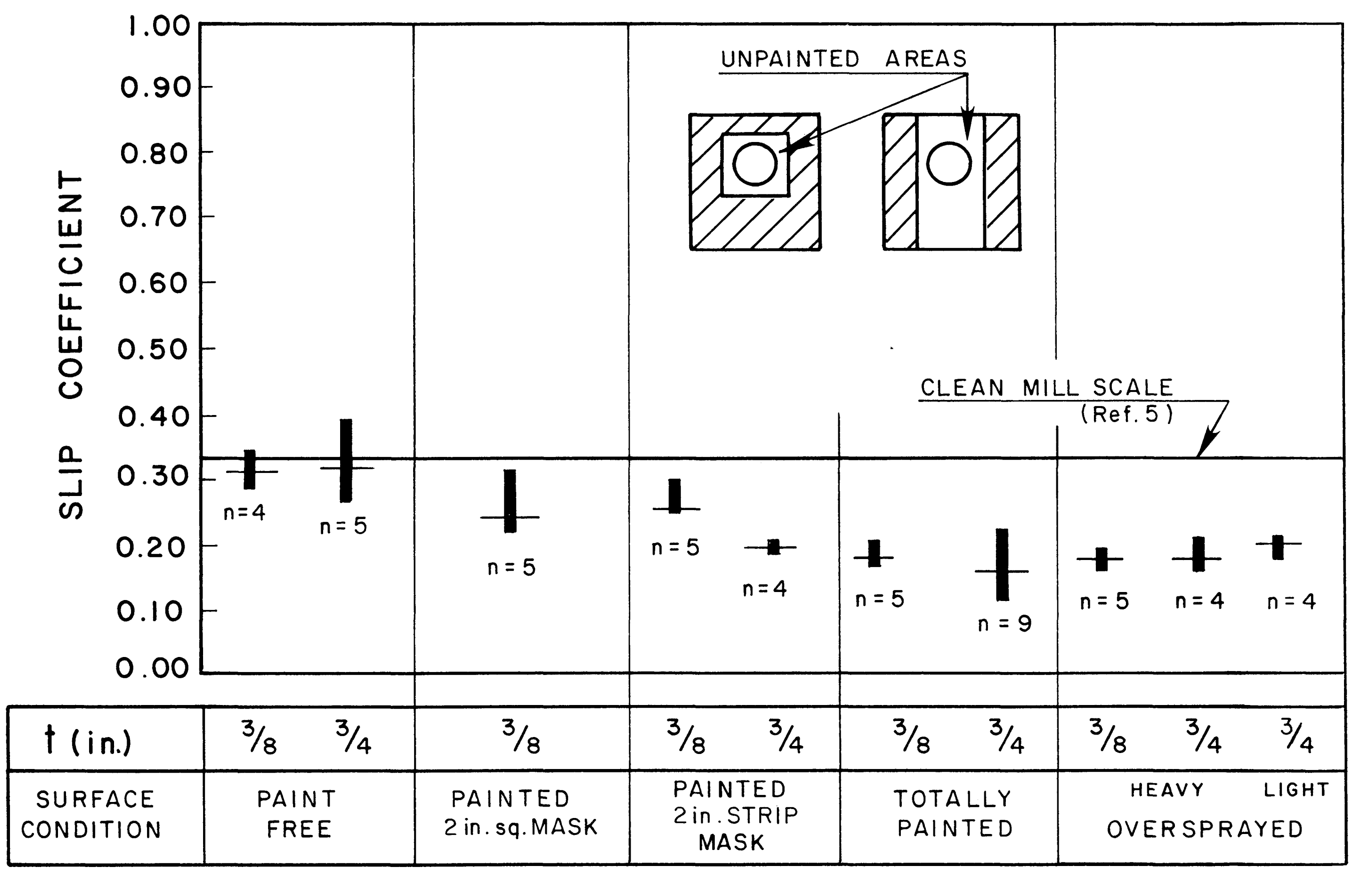


Fig. 4. Summary of results: Slip coefficients for paint-free and painted mill scale plates

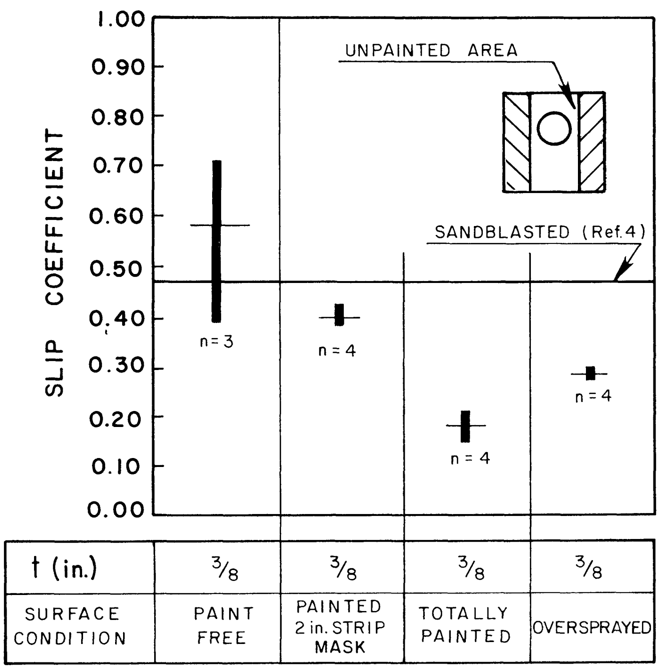


Fig. 5. Summary of results: Slip coefficients for paint-free and painted, sand-blasted plates

Full Paint Coating on Faying Surfaces

The red oxide primer paint coating resulted in a significant decrease in the slip coefficient for plates that were fully painted regardless of specimen thickness or prior surface condition. Results in Table 1 and shown in Figs. 4 and 5 indicate the average slip coefficient for mill scale specimens was reduced by 45%, from 0.31 to 0.17, while for sand-blasted specimens it was reduced by almost 70%, from 0.58 to 0.18. The type of surface prior to painting did not influence the slip coefficient of the fully painted surfaces (0.17 for mill scale and 0.18 for sand-blasted).

Over-spray on Faying Surfaces

Over-spray coatings on plates having clean mill scale surfaces prior to coating resulted in a decrease in the slip coefficient of the same order of magnitude as fully painted specimens, i.e. from 0.31 for paint-free surfaces to 0.17 for specimens with heavy over-spray and 0.19 for specimens with light over-spray.

Over-spray coatings on plates sand-blasted prior to coating resulted in a 50% reduction in the slip coefficient of the connections (from 0.58 to 0.29). This reduction, however, was not as high as observed when the plates were totally painted, where reduction was almost 70% (from 0.58 to 0.18).

Although the specimens were subjected to various degrees of over-spray, ranging from light to heavy as shown in Fig. 3, the results presented graphically in Figs. 4 and 5 show very little scatter. Therefore, it was not possible to establish a clear relationship between the degree of over-spray and the slip coefficient.

Incomplete Masking of Faying Surfaces

Incomplete masking around the bolt hole prior to the application of the paint resulted in a reduction in the average slip coefficient of both mill scale and sandblasted surfaces.

Two types of masking patterns were used for the ⅜-in. thick mill specimens: a 2-in. strip extending along the whole length of the plate specimens and a 2-sq.in. area around the hole. The results, shown in Fig. 4, indicate there was no significant difference in the slip performance of the connections between the two masking patterns. The 2-in. strip resulted in a 19% reduction in the average slip coefficient (from 0.31 to 0.25), while the 2-sq.in. mask resulted in a 22% reduction in the average slip coefficient (from 0.31 to 0.24).

Only one type of masking was used for the ¾-in. thick mill scale specimens: a 2-in. strip extending along the length of the specimens. The reduction in the average slip coefficient in this case was about 39% (from 0.31 to 0.19). The same type of masking was also used for the ⅜-in. thick sand-blasted specimens. As shown in Fig. 5, the reduction in the average slip coefficient for these specimens was about 31% (from 0.58 to 0.40).

Visual inspection of the fully painted contact surfaces after testing revealed the markings resulting from the relative movement of the plate during the slip tests covered an area which varied from 2 in. sq. to 2.9 in. sq., with an average of 2.5 in. sq. An example of the extent of the markings on the fully painted specimens is given in Fig. 6. In the case of the masked plates, the markings extended beyond the masked area by about 0.3 in., as shown in Fig. 7, indicating

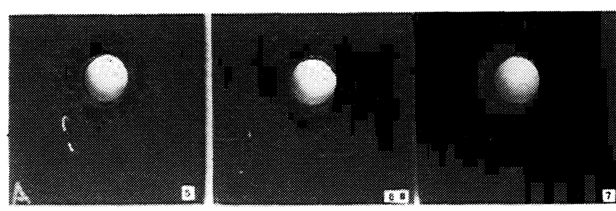


Fig. 6. Fully painted plates after testing

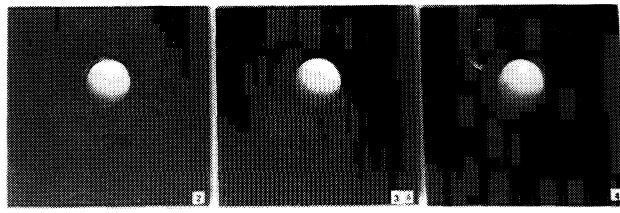


Fig. 7. Painted plates with a 2-in. sq. masked area

the faying surfaces extended approximately 0.8 in. from the edge of the hole and included a part of the painted area. This insufficient masking of the faying surfaces resulted in the reported deterioration of the slip performance of the specimens.

CONCLUSIONS AND RECOMMENDATIONS

Current design guidelines for friction-type connections suggest that:

> . . . regardless of the type of paint used, if the average over-spray paint film thickness is less than 0.00025 in., the faying surface is acceptable with no further corrective action necessary. If the average over-spray paint film thickness is between 0.00025 in. and 0.0005 in., the allowable bolt value must be reduced by 5% and a determination made, with the concurrence of the owner's engineer, as to whether or not removal of the overspray is necessary for the design intent.[2]

Since over-spray consists of randomly scattered paint droplets with varying intensity and thickness, it is not possible to establish design criteria based on paint film thickness.

Although various degrees of over-spray were considered in the present experimental program, the results indicated the slip performance of over-sprayed connections resembled more the behavior of painted connections, rather than the behavior of paint-free connections.

In addition, the present experimental program showed that masking of the faying surfaces with 2-in. wide tape did not improve the slip performance of friction-type connections sufficiently to render the connection paint-free.

Based on these results, it is recommended that:

1. Clause 3(c) of the RCSC Specification,[1] governing the condition of contact surfaces in Classes A, B and C friction-type connections, be extended as follows:

   Classes A, B and C (uncoated): Contact surface shall be free of soil, paint, overspray, lacquer or other coatings.

2. Recommendation 1, in Sect. G, Part III, in Chap. 2 of the AISC publication on *Quality Criteria and Inspection Standards*[2] be changed as follows:

   Inadvertent overspray of faying surfaces:

   Friction-type connections must be protected against over-spray in the same manner as they are protected against full painting, by masking of the faying surfaces. In the case of inadvertent over-spray, removal of the over-spray from the faying surfaces is necessary if the connection is to be treated as paint-free connection. Connections with over-spray not removed must be treated as fully painted regardless of the paint used.

3. Part 3 of the RCSC Specification[1] be amended to include the following statement:

   Masking of friction-type connections be extended 1-in. beyond the edge of the hole.

ACKNOWLEDGEMENTS

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REFERENCES

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