Center for Environmental Structure
ARCHITECTS · CONTRACTORS
2701 SHASTA ROAD · BERKELEY, CALIFORNIA 94708
TELEPHONE 415/841-6166

TORSION STRENGTH OF HEAT BENT JOINTS IN #10 REINFORCING BARS

Test Report on Steel Details in Concrete Truss for San Jose Homeless Shelter

by

R. Gary Black
(Vice President)

James McGuire
(Project Architect)

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DISCLAIMER

The authors and C.E.S. wish to make it clear that the tests performed and described in this report are by no means exhaustive. In fact, the contrary, they are highly limited in nature and scope. They were performed at the request of the subcontractor who is responsible for fabricating the concrete trusses in the dining hall of the San Jose Homeless shelter.

Anyone, involved with the Homeless shelter project or any other project, wishing to utilize the results presented in this report must do so at their own discretion, with a great deal of caution, and must assume full responsibility for any liabilities which may occur as a result.

ABSTRACT

This report presents the results of torsion tests performed on grade 60, #10 reinforcing bars which have been bent into a tight radius following application of heat with an acetylene torch. A total of twelve joints were tested under various degrees of stress. Eight joints were tested in the elastic range, four were tested in the inelastic range.

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1. INTRODUCTION

1.1 Background

A concrete truss is currently design and engineered for the dining hall of the San Jose Homeless shelter. The span is approximately 30 feet. The truss has an average thickness of 5 inches, and a bottom cord which is made from three arches.

In-plane forces; (vertical and lateral) are carried through the truss in conventional fashion. The top cord is predominately a compression member, and the bottom cord principally a tension member. Since the joints are moment connections rather than pins, however, moment and shear forces are induced into the cord members in addition to the axial forces. Web members also experience moment and shear forces, but they are principally axial force members carrying both tension and compression.

Out-of-plane forces; which could be generated in an earthquake when the building is exposed to forces parallel to the long axis of the building, create out of plane bending and shear forces in the top and bottom cords. Under this type of seismic loading, web members experience torsion. To resist the torsion forces the web members are reinforced with a single #10 bar of grade 60 steel which is placed in the center of the web section and terminates in the cages of the top and bottom cords. These same bars are used to carry the tension and compression forces generated by in-plane forces.

1.2 Objective

The objective of the tests described in this report was to empirically evaluate a method of anchoring the ends of the #10 bars so that they could develope the required torsion. The proposed method consists of bending 6 inch tails on the ends of the #10 bars using heat. It was necessary to bend the bars with heat because in order to gain the required embeddment for tension and compression forces the bends had to be made with a very tight radius (approximately 1 or 2 bar diameters) as opposed to the normally specified 8 bar diameters. Concern about the strength of the bend arose because reinforcing bar is normally bent cold.

1.3 Scope

Six bars were tested, with each bar having two bends. Because of the testing procedure, a total of twelve joints (tight radius bends) were tested.

Four of the joints were tested at loads which were equal to double the maximum forces expected in the truss. Another four joints were tested at loads equal to 4 times the maximum forces which are expected to occur in the truss, but at values which were just within the elastic range for 60 ksi steel. The remaining four joints were tested until the material between the joints reached full plastic yield.

2. TESTING PROCEDURE

2.1 Specimen Preparation

The test bars were grade 60 rebar, size #10, having a length between 4 feet and 8 feet. Each of the test specimens were prepared by heating a point along it's length to red hot with an acetylene torch fitted with a 6 hole rose bud heating tip. The size and temperature profile of the point is described under instrumentation. When the heated point of the bar had reached red hot the bar was clamped into a vice and bent by hand using an extension pipe.

Two bends (approximately 90 degrees each) were made in each bar. The bends were made in opposing directions and were between 5 inches and 8 inches apart, Figure 1. Once the bends were completed, the bar was allowed to cool in air until it reached room temperature.

2.2 Instrumentation

Temperature sensitive crayons were used to roughly determine the temperature profile of the heated zone. The maximum temperature crayon which we had available was a 1500 degree Farenheit crayon. In addition, two other crayons were used; a 1250 degree and a 1000 degree.

Once the zone was heated to a point which enabled easy bending, the crayons were rubbed against the steel to determine the temperature. The red hot zone, which was two inches in length was hotter than 1500 degrees Farenheit by virtue of the fact that the 1500 degree crayon melted when rubbed against the steel at that point. At a point approximately two inches on either side of the red hot zone, as measured from the center of the zone, the 1250 degree crayon would not melt. At approximately three inches on either side of the red hot zone the 1000 degree crayon would not melt. Figure 2 shows the temperature profile of the heated zone.

2.3 Testing

The tests were performed in the Architecture shop at the University of California, Berkeley. The tests were done in such a way so as to allow for simplicity of set up and also allow for visual inspection of the joints at all times during the test. Once the test specimens were prepared they were clamped to a table with one end of the bar hanging free. A 20 foot long by 3 inch diameter extension bar was slipped over the free end of the test specimen and a known weight was hung on the end of the extension bar. By multiplying the moment arm times the weight (184 lbs) it is easy to determine the amount of torque which is being applied to the heat bent joint, Figure 3.

In all, six specimens were tested. The first two were tested at a torque equal to 2 times the maximum torsion expected in the web members of the truss. The torque for specimens one and two was 7,360 lb-in (184 lbs X 40 in.) Specimens 3 and 4 were tested at 13,248 lb-in, or about 4 times maximum torsion in the web members of the truss. This torque just corresponds to the theoretical onset of yield in the outermost extreme fiber of the bar. Specimens 5 and 6 were tested until the portion of the #10 bar between the bends became fully plastic. This occured visibly at a torque of about 20,000 lb-in. Figure 4 shows an actual yield test specimen before and after testing and figure 5 summarizes the tests. On the basis of the Mises criterion the theoretical onset of yielding should occur at 0.577 tensile yield.(1) This criterion would indicate that yielding would just begin on the outer surface of the bar at a torsional stress of 34,620 psi, which would correspond to a torque of 13,300 lb-in.

(1) Crandall Dahl Lardner "Mechanics of Solids"...

3. RESULTS

An experimental study of 12 joints which were bent using heat and then subjected to torsion forces was performed. In all cases the heat bent joint appeared to perform well under the prescribed loading. Even in the cases where the portion of the bar between the joints was stressed to full plastic yield no cracking or breaking of the joints was observed.

It must be re-stated, however, that the tests described in this report are of a limited nature. No strain gages, photogrammetry, LVDT's, or any other instrumentation typically used in a structural test were employed. No hysteretic tests were performed. In addition, 12 joints is a relatively small sample.

Although it was not possible to study the behavior of the joints on a micro level the test results do indicate that on the macro level at least, one should not expect a structural failure in a heat bent joint when subjected to a torsion force. On the macroscopic level, the test results do give a degree of confidence (within the limitations of the tests themselves) in the heat bent joint detail as a method for resisting torsion forces in the truss.

4. RECOMMENDATIONS FOR FIELD FABRICATION

During the heating and bending operation certain rules should be observed to help insure a good bend. These are outlined as follows.

1. The steel should be brought to red hot without overheating the surface to a point where the metal begins to run. This requires that the torch be held at least two inches away from the surface at all times. It is necessary to heat the metal SLOWLY.

2. The red hot zone should be about 2 inches in length. If it is shorter than 2 inches the outside radius of the bend will be over stressed. If the zone is longer than 2 inches more of the bar will be heated above 1200 degrees which may negatively effect the behavior of the bar under tension forces.

3. Once the metal is red hot the bend should be made. It is important that the bend be made SLOWLY and STEADILY.

4. As the bend is being made it is necessary to observe the outermost surface of the steel at the outside radius of the bend. If the bar has been properly pre-heated the steel will flow plastically into a smooth bend without any cracks or separation of the material. IF ANY SEPARATION OF STEEL IS OBSERVED DURING THE BENDING OPERATION THAT BAR MUST BE DISCARDED. Do not try to re-heat or repair the bar in any way.

5. Allow the heated bent bar to cool slowly in air. Do not dip it in water or pour water on any part of the bar to accelerate cooling. Quenching the heated bar could have a negative impact on the ductility of the material.

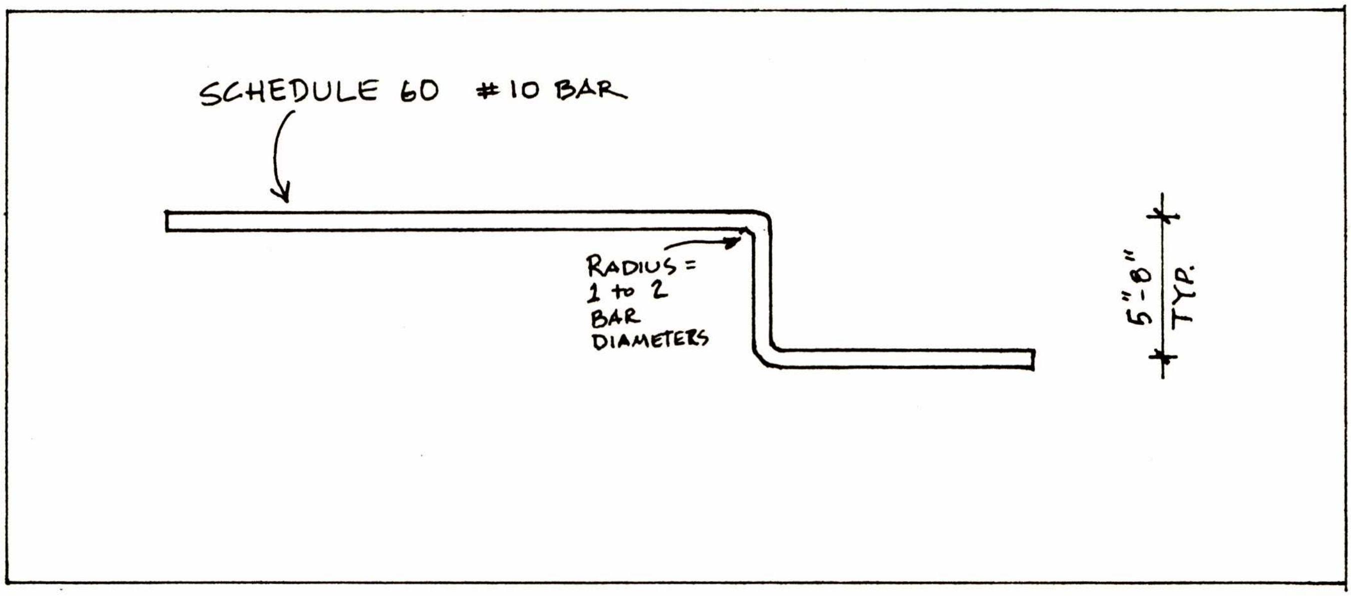


FIGURE 1. SPECIMEN PREPARATION

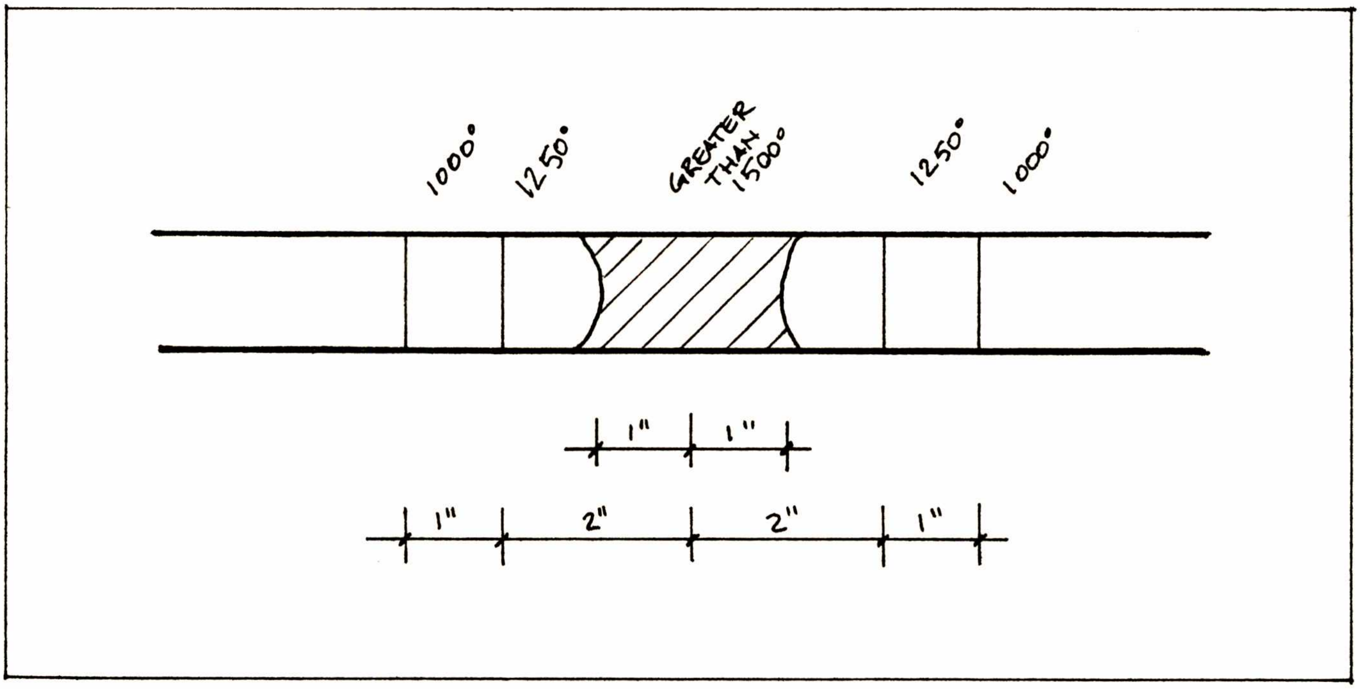


FIGURE 2. TYPICAL TEMPERATURE PROFILE

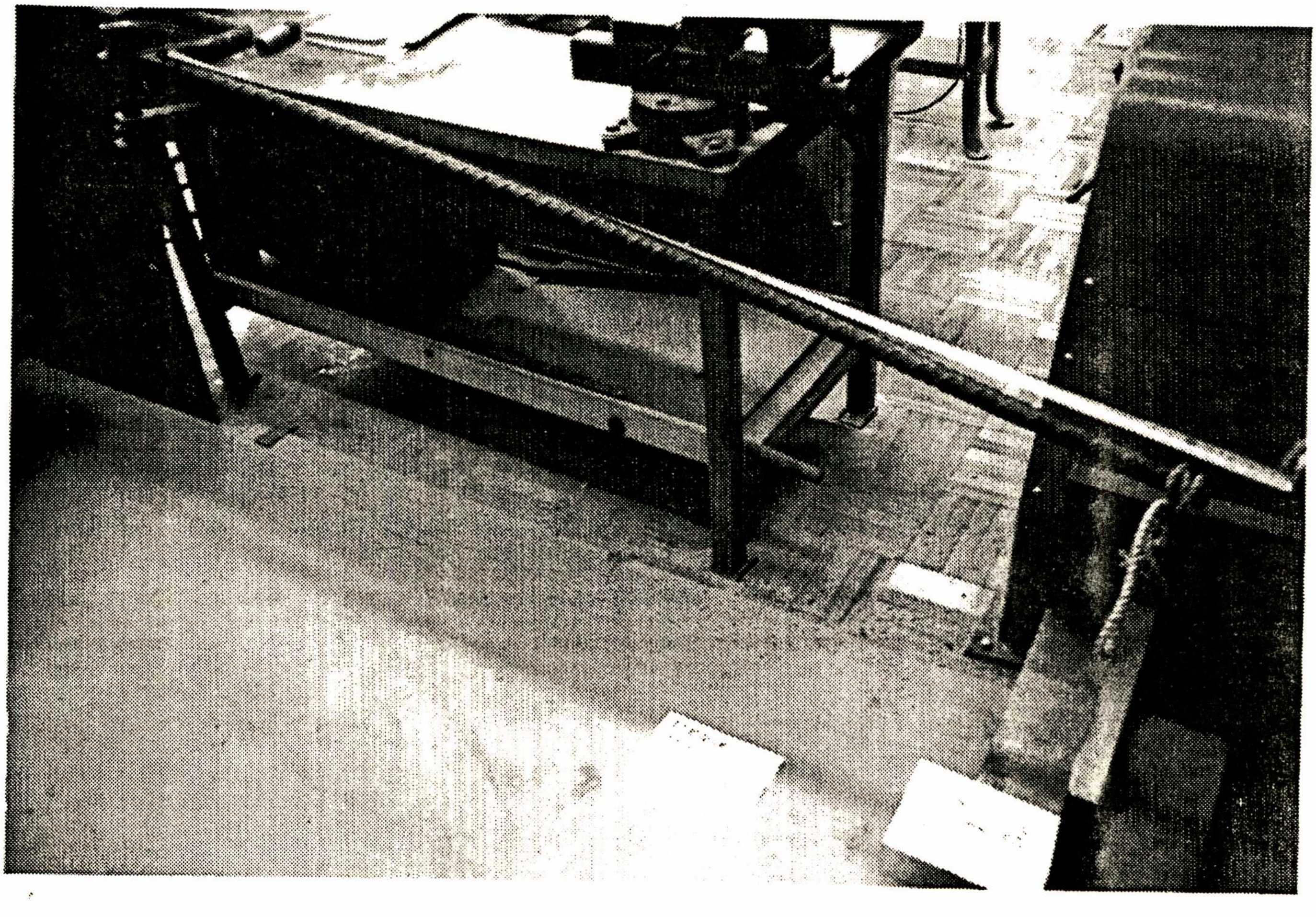
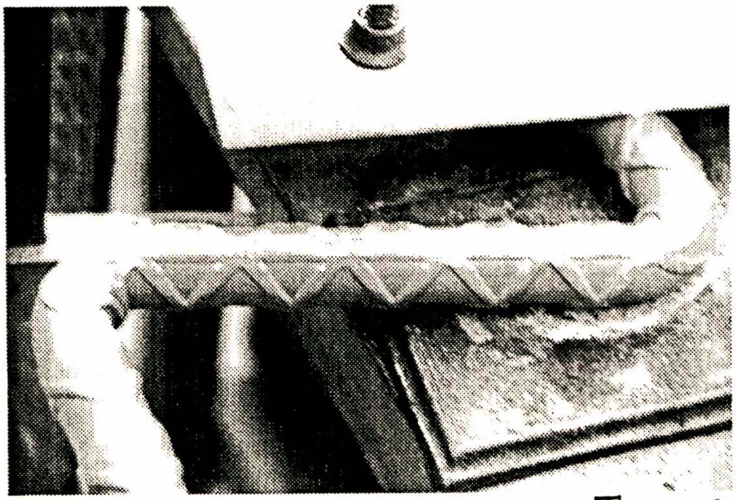
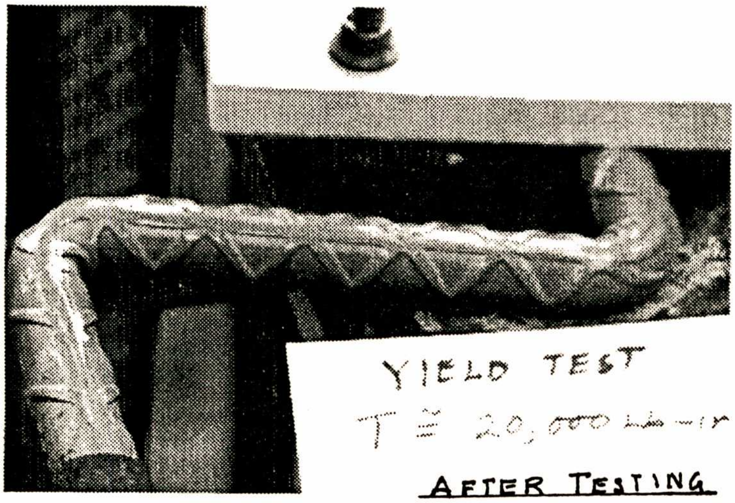


FIGURE 3. TEST SET-UP



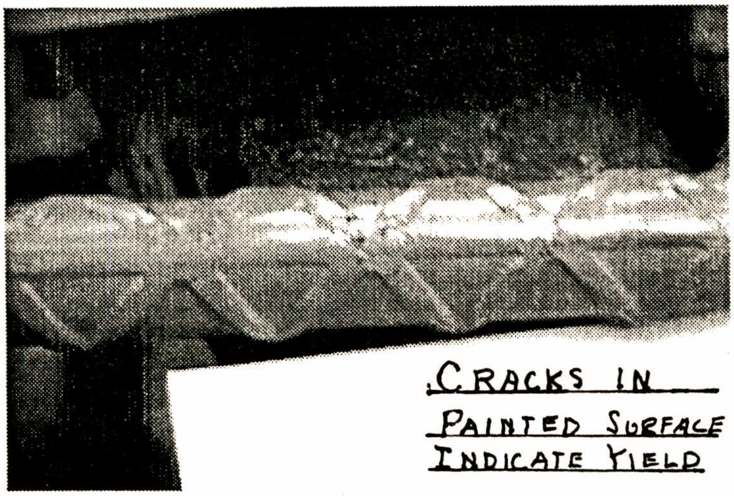
BEFORE TESTING



YIELD TEST

$T \cong 20,000$ lb-in

AFTER TESTING



CRACKS IN
PAINTED SURFACE
INDICATE YIELD

FIGURE 4. YIELD TEST SPECIMEN

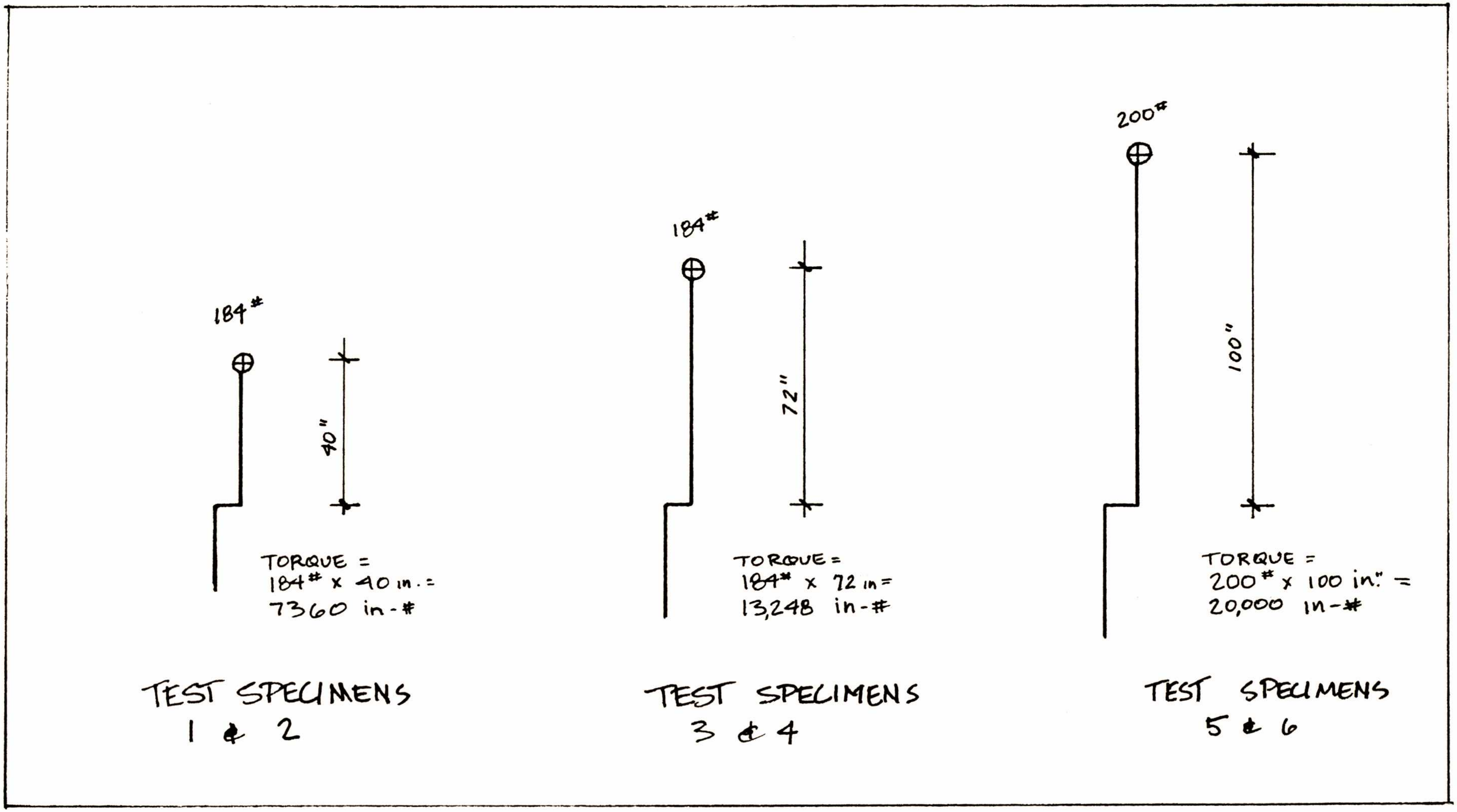


FIGURE 5. SUMMARY OF TESTS PERFORMED