REPORT OF COMMITTEE ON MATERIALS AND CONSTRUCTION

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BEND TESTING OF STEEL

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SYNOPSIS

An improved machine for making the bend test is described The bend is made in this apparatus in a theoretically correct manner It is adapted to use in any universal or compression testing machine The significance of the bend test is discussed and data are submitted showing the relation of size of bar, shape of bar and angle of bend to the diameter of the pin around which the specimen is bent Data are presented relative to the elongation at rupture under the bend test as compared to the elongation produced by failure under simple tension

In the report of the Investigation of "Use of Rail Steel Reinforcement Bars in Highway Construction," presented at the Eleventh Annual Meeting of the Highway Research Board, the committee recommended that "Consideration be given by the proper organizations to the formulation of a correct method of test bending reinforcing bars "

This recommendation led to the initiation of the research project of which this paper is a progress report

In the standard specifications of the American Society for Testing Materials for Billet-Steel Concrete Reinforcing Bars (A-15–30) and for Rail Steel Concrete Reinforcing Bars (A-16–14) there is no requirement as to method of making the bend test other than that the bar shall be bent around a pin of a specified diameter depending upon the size, form and grade of material composing the bar. The bend is made through a specified angle of either 90 or 180°. The bend test as made does not permit of a quantitative measure of the bar's behavior during the test The bar either fails or passes the test and no statement as to the margin by which it passes or fails is possible. It would seem however, that such variables as rate of bending, amount of lateral restraint and force applied at the compression face during the test would exert a marked effect upon whether the bar did or did not pass the test. A study of the test data secured during the progress of the committee's investigation indicated very satisfactory uniformity in the physical properties of both billet steel and rail-steel bars with the exception of the results of the bend tests Bend tests of high-elastic limit steels showed a very much greater dispersion among results of different laboratories than any other physical property tested In view of the uniformity of the other physical properties, it seemed reasonable to suspect that the methods of bend testing might be at fault For the lower-elastic-limit steels the bend test as made is not indicative of any particular property as it is very difficult to cause failure of these ductile materials by bending

While the bend test of metals is one of the oldest tests ever applied it is not known, when applied to reinforcing bars, whether it means anything other than that the bar may be bent in the manner chosen for the test without causing the failure of the bar It has long been the author's opinion that this is the exact significance of the bend test that its sole function is to indicate whether or not it is likely that the particular steel under consideration can be satisfactorily bent for fabrication Although there has been but little research into the significance of the bend test, some of the reports seem to indicate that perhaps it does show properties different from those brought out by the standard tests for ductility such as elongation and reduction of area Some of the data in this investigation indicate that there was considerably greater ductility revealed by the bend test than by the tension test but the data are not sufficient to warrant any definite conclusions

In starting the investigation one of the first considerations was the development of a suitable bending device which would comply with the following conditions

(1) The device should bend the bar around the pin specified with the least possible force

(2) The device should make the test without the introduction of lateral forces due to roller friction or dragging of the metal across small rollers

(3) It should be possible to control the rate of motion so that any reasonable bending speed could be secured

(4) It should be possible to make the test on pieces of reasonably short length so that special test specimens need not be required

None of the machines commercially available would satisfactorily meet these conditions One type of machine in common use in laboratories and in fabricating shops bends the bar around the pin by a sort of wiping action This introduces large lateral forces producing tension on the outer fibers of the bend in addition to the bending stress Some of the machines in the fabricating plants are equipped with a follower which advance the bar during the bending operation thus reducing this tendency

The other type in common use consists of a device which forces the bar between two rollers bending it around a tap or pin of the specified diameter All such machines with which the author is familiar use relatively small rollers. The span between rollers is very short and accordingly the force required to bend the bar is great. These rollers, turning upon small bearings, exert tremendous lateral restraint upon the bar during the test as witnessed by the heavy scoring on the rollers as the bar is dragged across them.

After considerable experimentation with different devices and the trial of several sizes of the apparatus finally developed, the machine shown in Figure 1 was considered to meet these requirements.

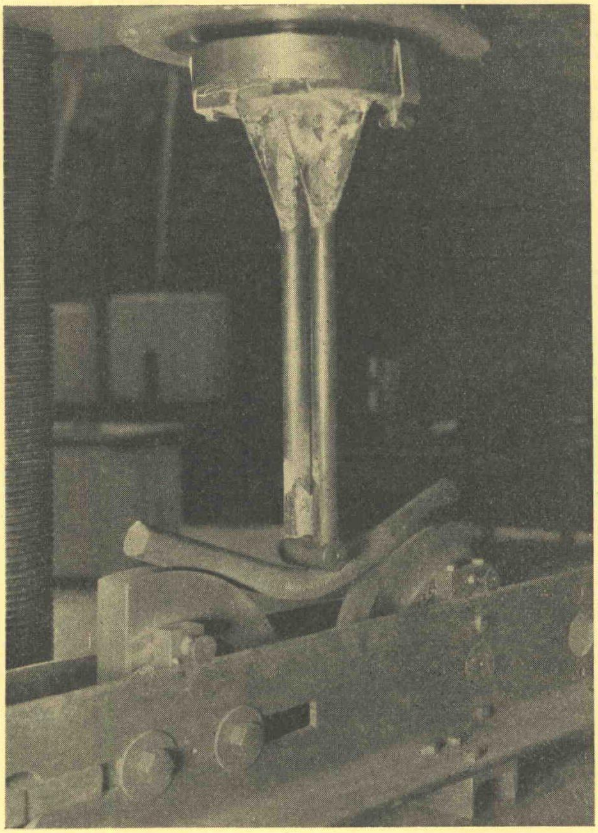

Figure 1. Bend Test Machine in Use

This device is simple and adapted for use in any testing machine or press. It consists of two cast iron segmental rollers of six inch radius mounted on hardened steel pins two inches in diameter. These are mounted in a frame of 4 by 6 by $\frac{3}{8}$ inch standard steel angles. One bearing is made adjustable so that the distance between rollers may be properly set to bend the bar to be tested. The end thrust of the movable roller is carried by a one-inch steel screw which is also used to set the bearing in the proper position.

The upper edge of the frame is graduated in inches and a pointer on the bearing frame indicates the distance between faces of the segmental rollers. This makes it a very simple matter to space the rollers correctly for any size of bar and pin. The total weight of the machine is 175 lbs.

The load is applied to the bar by the simple device shown in Figure 1. It consists of two $1\frac{1}{4}$ inch steel rods welded to a base plate which is fitted with clamps for attachment to the spherical head of the testing machine. The other ends of the rods are welded together with a fillet $\frac{1}{4}$ inch wide and the ends milled with a V-shaped groove to hold the hardened steel pins around which the bar is to be bent. Small pins rest in this groove as shown. Large pins as shown in Figure 2 are arranged so that they may be attached to the load applicator. To bend a bar through 180° requires a movement of six inches plus the diameter of the bar plus the radius of the pin. Bending will always start with a span of 12 inches plus the diameter of the pin plus twice the thickness of the

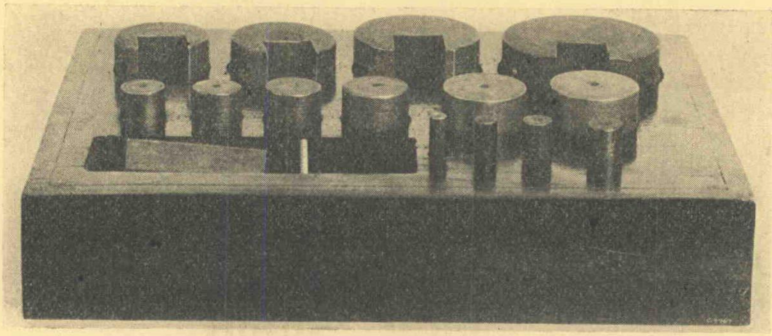

Figure 2. Pins Used for Bending Mandrels

bar. It is this long span which causes the bar to bend under relatively small loads. To bend a $1\frac{1}{4}$ inch round bar about a pin of its own diameter required a load of 9600 lbs., about one third that required for the Olsen machine with small rollers.

The only comparison of results with two different bending machines at present is possible by means of the loads required to make the bends. If some quantitative methods were developed for measuring the effects of a bend test where failure did not occur other comparisons should be possible.

It is believed that the method shown here is entirely feasible and can be used to show quantitative results. As a means of measuring the effect of bending the amount of deformation between gage marks placed on the specimens was used. Punch markings are objectionable because an indentation is likely to cause a fracture to start prematurely when the metal is stressed. A more desirable mark would be one that did not break into the surface in any way.

This problem was solved by using scratches on copper plating the

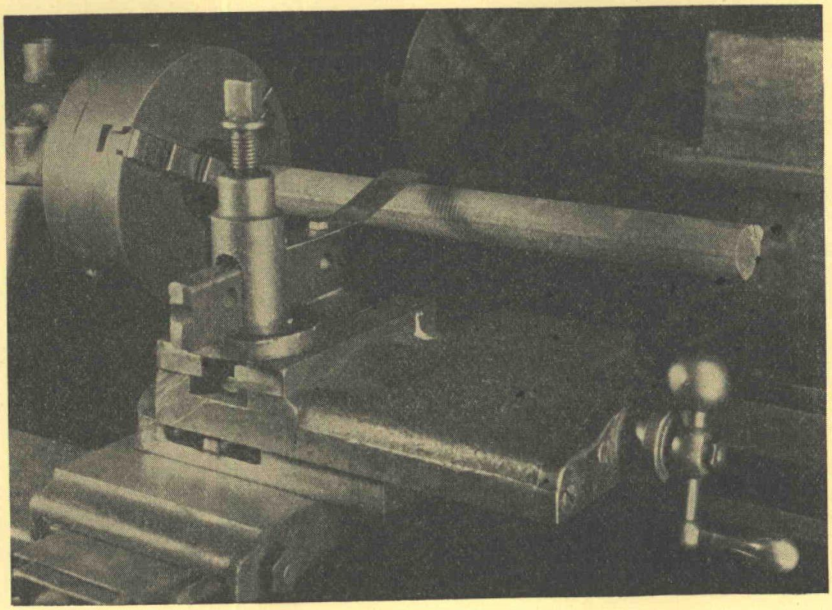

Figure 3. Method of Making Gage Marks

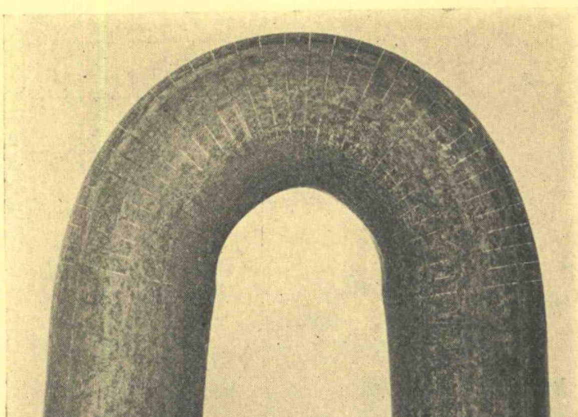

Figure 4. Bar after Being Bent through 180 Degrees ($1\frac{1}{4}$-Inch Diameter)

way machinists do in laying out work. The bars were pickled in dilute sulphuric acid to loosen the scale and to provide a clean surface for plating. An hour in the pickling solution was usually sufficient to accomplish this Plating was done by swabbing the bars with a solution of copper sulphate The gage marks or scratches were made $\frac{1}{8}$ inch apart by a special tool mounted in the toolpost of a lathe as shown in Figures 3 and 4.

The deformation was calculated by measuring the increased distance between lines at the location desired and subtracting the original distance This was measured for a one-quarter inch gage length rather than one-eighth, as the larger distance offers less chance for error The accuracy of this measurement was to the nearest 0 005 inch, so the limits of accuracy were well within plus or minus two per cent

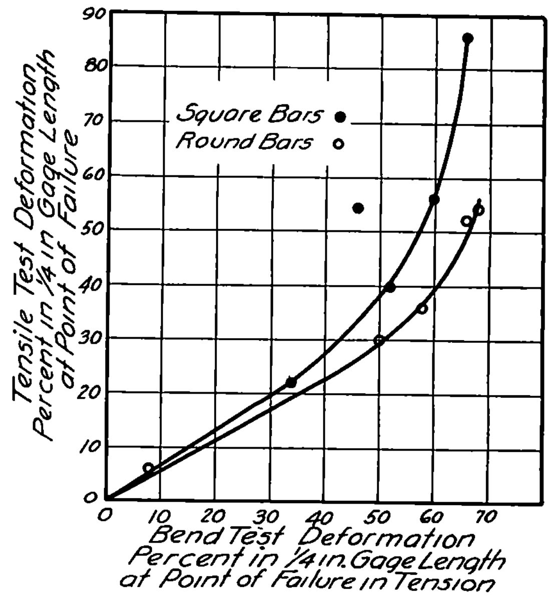

Figure 5. Curves Showing Possibility of Correlation between Band and Tension Tests. Data from Table I. All bars bent around one thickness or diameter

The measurement of deformation in bending is easily made on the outside of the bend but not so easily on the inside The compressing of the steel causes the lines to be harder to see and the pin pressure obliterates them More experimentation will be required to get a satisfactory means of protecting the inside gage marks during the bending operation

Using this method for observing the effects of the bend test the following studies were made

A comparison of the elongation in $\frac{1}{4}$-inch gage length at the point of failure of a specimen in a bend test and a simple tension test is shown in Figure 5 It was very difficult to get steel, that would fail in a bend test even when bent around its own diameter. The few results shown

TABLE I

Comparative Results of Tension and Bend Tests

Bar no	Description	Tension test: Yield point	Tension test: Ultimate	Tension test: Deformation in ½ inch	Bend test: Dia of bend	Bend test: Angle of bend	Bend test: Deformation in ½ inch
		lb per sq in	*lb per sq in*	*per cent*	*in*	*deg*	*per cent*
B-1	½ in rd	58,400	102,500	54	½	180	68
C-1	½ in sq	59,500	101,000	54	½	123	46
D-1	⅝ in rd		120,000	36	⅝	133	58
E-1	¾ in rd	63,600	116,700	30	¾	104	50
F-1	1 in rd	58,900	108,000	52	1	130	66
G-1	1 in sq	55,500	108,000	40	1	80	52
G-2	1 in sq	54,700	99,300	54	1	80	46
H-1	1¼ in sq		168,500	22	1¼		34
M	⅝ in sq	62,100	94,800	56	⅝	182	60
M	⅜ in sq	75,000	82,200	86	⅜	150	66
M	⅜ in rd		178,800	6	⅜	25	8

Note Bars *M* were heated to 1800 degrees Fahr then quenched in brine before testing Blank spaces in "Yield Point" column were caused by it not being noticeable enough to record with any degree of certainty

TABLE II

Physical and Chemical Properties

Spec no	Description	Tensile test: Yield point	Tensile test: Tensile strength	Elong in 8 in	Bend test: Elong in ½ in	Bend test: Angle of bend	Bend test: Dia of pin	Chemical analysis: Carbon	Chemical analysis: Phosphorus	Chemical analysis: Sulphur
		lb per sq in	*lb per sq in*	*per cent*	*per cent*	*degrees*	*inches*			
1	1¼ in sq Def	43,450	78,300	25 5	32	180	3 75	0 39	0 030	0 060
2	1¼ in sq Pl	34,000	55,800	35 6	72	180	1 25	0 21	0 008	0 043
3	1¼ in rd Pl	33,450	53,800	38 0	60	180	1 25	0 17	0 002	0 050
4	1 in sq Def	45,800	79,200	22 0	44	102	1 00*	0 35	0 014	0 059
5	1 in sq	36,500	54,600	36 0	68	180	1 00	0 15	0 007	0 054
6	1 in rd Def	53,650	85,500	24 9	40	180	2 00	0 42	0 040	0 066
7	1 in rd	34,300	53,550	34 5	60	180	1 00	0 14	0 008	0 044
8	¾ in sq	36,400	57,700	29 7	72	180	0 75	0 19	0 012	0 075
9	¾ in rd	40,300	60,100	30 5	64	180	0 75	0 19	0 014	0 095
10	¾ in. rd Def	48,500	84,900	24 3	68	180	0 75	0 35	0 037	0 077
11	⅝ in rd	39,700	59,900	30 6	68	180	0 625	0 15	0 024	0 095
12	⅝ in rd Def	51,700	81,200	23 3	60	180	0 625	0 35	0 038	0 093
13	⅝ in sq	36,800	56,400	32 0	72	180	0 625	0 16	0 013	0 070
14	½ in sq	39,500	56,000	32 0	72	180	0 500	0 14	0 015	0 102
15	½ in sq Def	69,900	111,000	11 8	68	144	0 500*	0 46	0 101	0 137
16	½ in rd	42,200	56,600	30 0	64	180	0 500	0 14	0 017	0 071
17	½ in rd Def	78,100	117,500	10 5	60	180	0 500	0 49	0 102	0 070
18	½ in sq	37,700	52,400	30 3	60	180	0 375	0 12	0 009	0 072
19	⅜ in rd	39,400	51,600	30 2	60	180	0 375	0 10	0 016	0 130
20	⅜ in rd Def	51,600	72,700	28 0	68	180	0 375	0 30	0 003	0 073

* Broke.

in Figure 5 while not sufficient to warrant drawing definite conclusions indicate the liklihood that a very definite relationship exists. The data are shown in Table I.

An interesting fact is that with one exception all bars that failed on the bend test failed in compression first. This tendency has also been pointed out by Dr. Wyss, a Swiss scientist. Mr. H. P. Bigler, Engineering Secretary of the Rail Steel Bar Association, also commented on this in his discussion of the report of Investigation of the Board's special committee made last year. Mr. Bigler showed micrographs made in

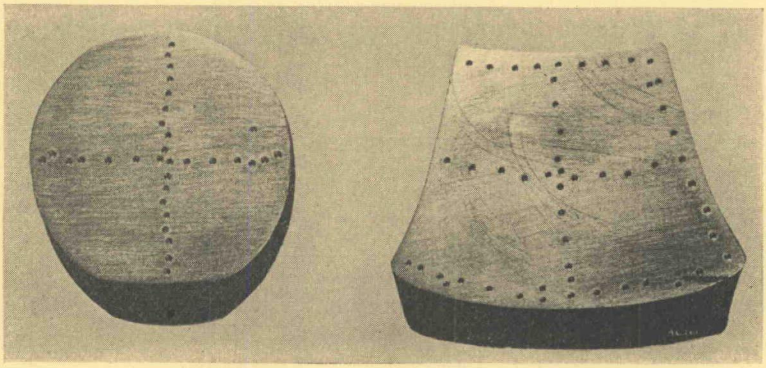

Figure 6. Sections Cut from Bends

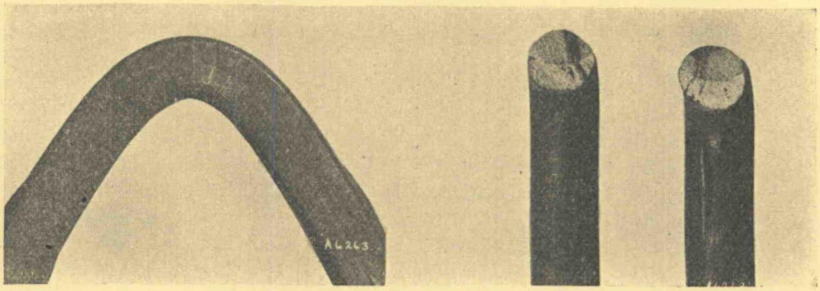

Figure 7. Typical Bend Failures

their laboratories that indicated the most serious deformation occurred on the compression side (see Figure 7).

Figure 6 shows the cross section at the bend of a square and round bar. It will be noted that the square bar at the compression face shows very drastic deformation. It is believed that bends are much more injurious to square bars than to round bars and that some recognition should be given this fact in the standard specifications.

A study was also made of the relation of bar size to deformation on the tension side as affected by variations in the size of pins about which the bars are bent. Table II shows the physical and chemical properties of the bars used in this test.

These data are platted in Figures 8 and 9 They confirm the indications from other investigations that the deformation is practically constant regardless of the size of the bar It will again be noted that the square bars give much more erratic values, particularly for small diameters, than do the round bars

The effects of varying the angle of bend when various size bars were bent about pins of d = t and d = 3t were also investigated These data are platted in Figures 10, 11 and 12

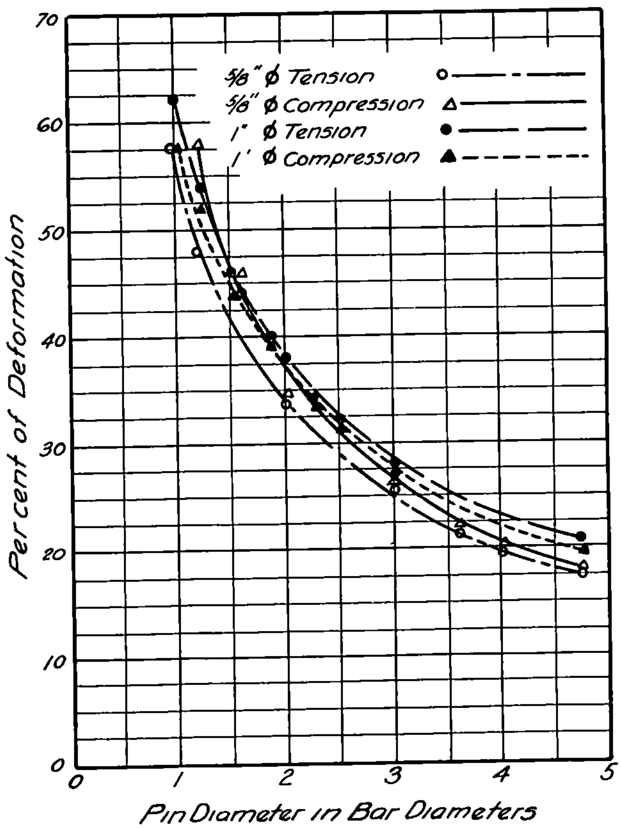

Figure 8. Relation of Pin Diameter in Bar Diameters to Deformation

Figure 11 shows that for the ⅝-inch bars the deformation was increased up to the angle of 180 degrees while for the 1 inch and 1¼-inch bars the deformation became constant at about 140 to 150 degrees

Figure 12, showing the results of bending around pins of three times the diameter of the bar, indicates that a maximum deformation is recorded at about 90 to 100 degrees for the larger bars and at about 150 degrees for the small bars It will be noted that there is a marked tendency for all to come together at about a common value as the 180 degree angle is approached.

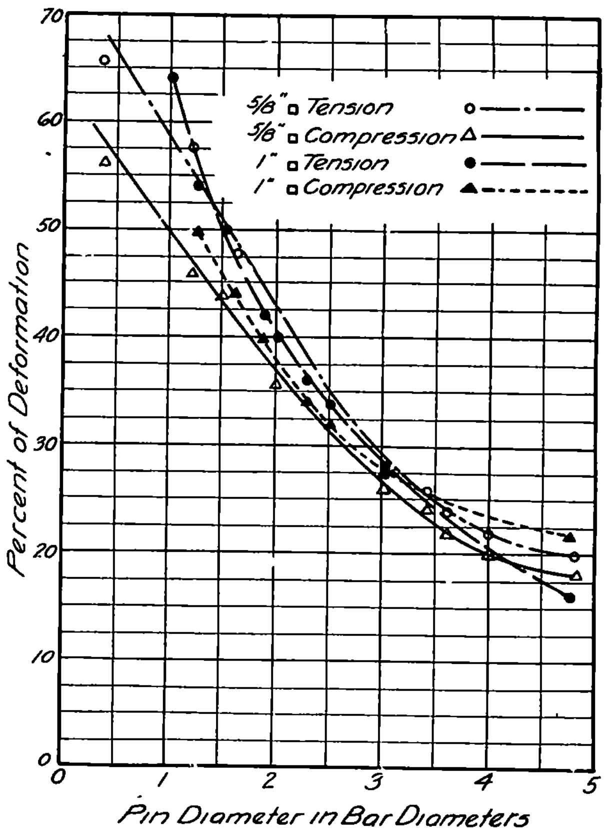

Figure 9. Relation of Pin Diameter in Bar Diameters to Deformation

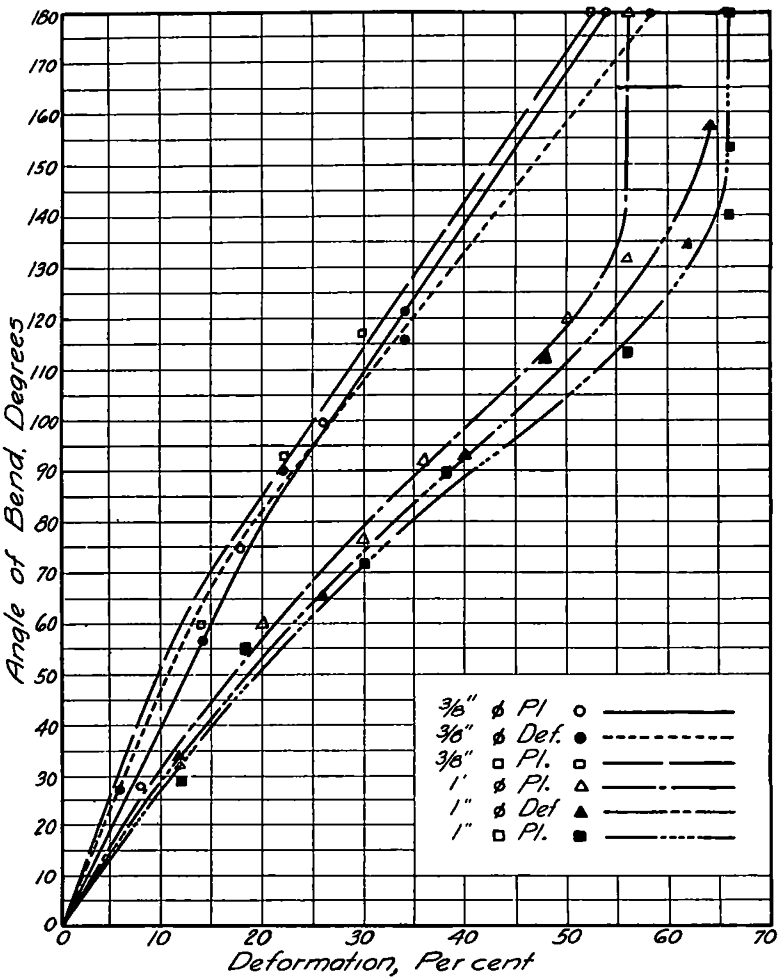

Figure 10. Relation of Deformation to Angle of Bend. $d = t$

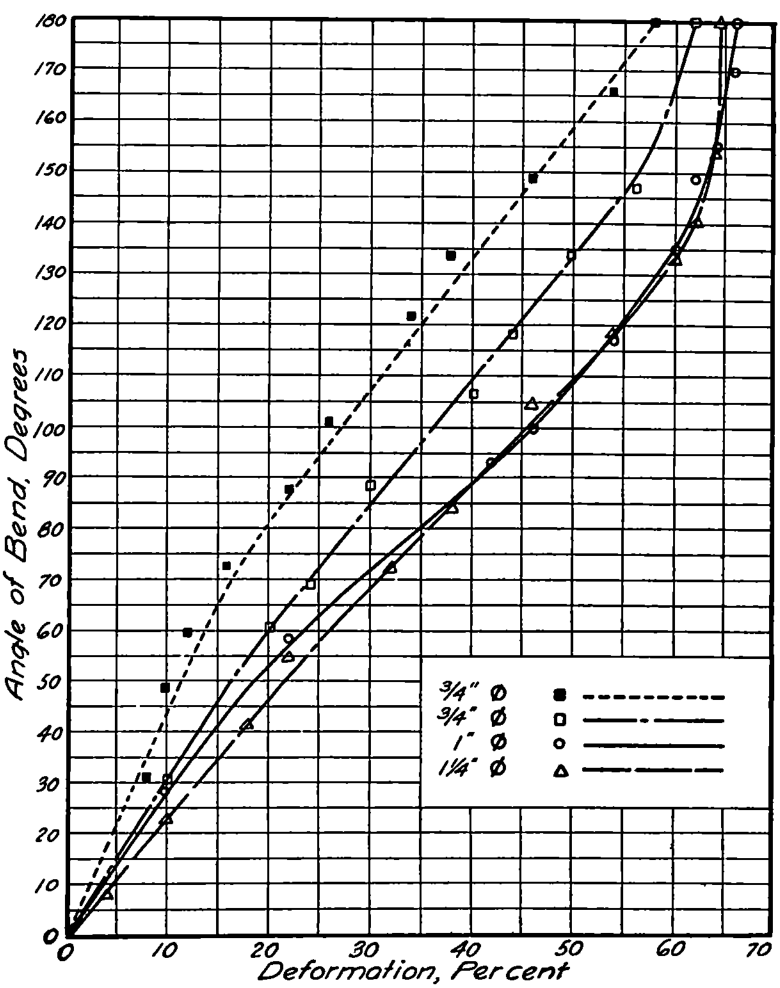

Figure 11. Relation of Percentage of Deformation to Angle of Bend. $d = t$

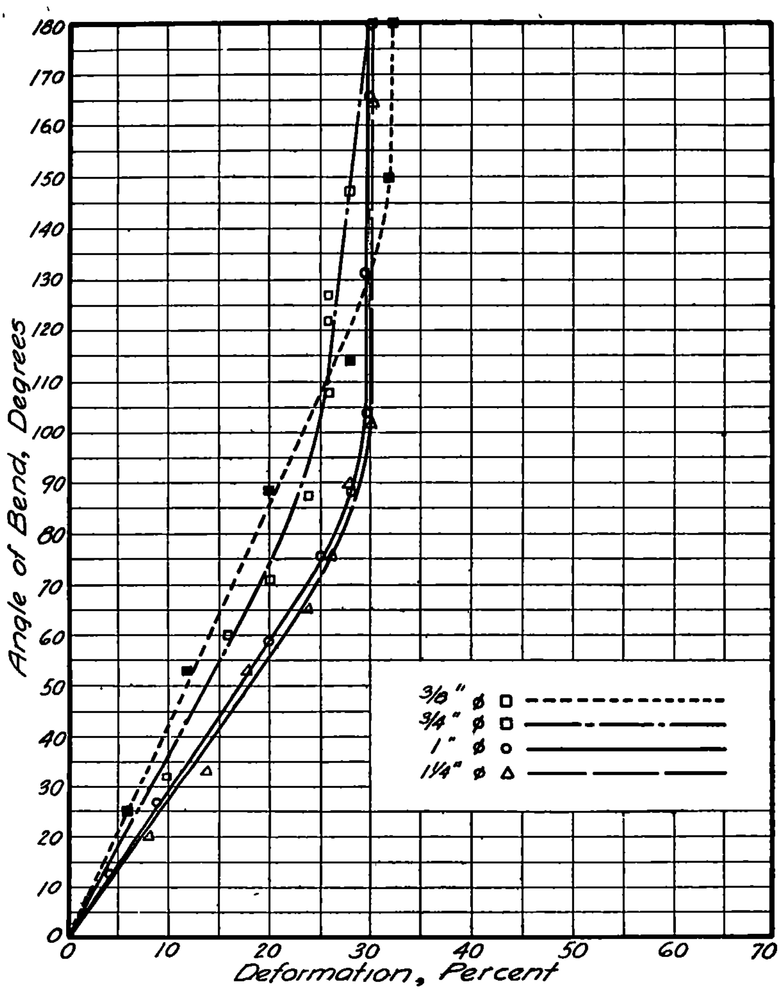

Figure 12. Relation of Percentage of Deformation to Angle of Bend. $d = 3t$

CONCLUSIONS

From theoretical considerations and from experience in operation, the machine developed in this investigation was found to be much superior to any others with which the author is familiar

The method of gage marking the specimens as described in this paper seems to offer possibilities for getting a quantitative measure of the results of the bend test

It appears that there is probably a definite correlation between the deformation in a simple tension test and the tensile deformation in a bend test Considerable work must yet be done before the relation can be accurately shown

There appears to be no reason for changing the ratios of the diameter of the pin to the thickness of the bar with varying sizes of bars

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Appendix II Report of Committee A-1 Proceedings of A S T M, Vol XIII

DISCUSSION

ON

BEND TESTING OF STEEL

MR M H ULMAN, *Pennsylvania Highway Department* The A. S T M specifications do not sufficiently cover the quality, relative to the various uses to which hard grade steel reinforcing bars are subjected I refer to the dowel bars in half-width construction, which are bent to ninety degrees and then straightened prior to the construction of the additional concrete traffic lane. We have found in many instances that this type of steel, although meeting the A. S. T. M cold bend test, will fracture on straightening I, therefore, feel that the A S T. M specifications should be sufficiently inclusive to include such conditions of service

PROFESSOR SCHOLER. In regard to Mr Ulman's remarks, the bend test should be made to indicate whether the bar meets the particular requirements to which it will be subjected in use If you expect to bend the bar and straighten it out again that should be referred to as a requirement in the bend test of bars for that particular use However, in such an instance as Mr Ulman describes it will be found that the property of the steel which makes it desirable for use in fabrication tends to cause it to function poorly in service To bend and straighten easily requires a low elastic limit material and to render efficient service as a dowel a high elastic limit material would be indicated.

MR H P BIGLER, *Rail Steel Bar Association*· The revised specification under consideration by the American Society for Testing Materials provide that the bend shall be made without any restraint of the bar on any part of the machine—that is, there shall be no sliding friction, no clamping of the parts, no jerky motions such as might be had by sliding of the bar on intermittent application of pressure