1-1-1958

Wedge fastenings for wood mine pins

C. B. Koch

William H. Reid

Digital Commons Citation

Koch, C. B. and Reid, William H., "Wedge fastenings for wood mine pins" (1958). *West Virginia Agricultural and Forestry Experiment Station Bulletins*. 411T.
https://researchrepository.wvu.edu/wv_agricultural_and_forestry_experiment_station_bulletins/641

BULLETIN 411T, FEBRUARY 1958

Wedge Fastenings For Wood Mine Pins

EST VIRGINIA UNIVERSITY AGRICULTURAL EXPERIMENT STATION

THE AUTHORS

Authors of *Wedge Fastenings for Wood Mine Pins* are C. B. Koch, Assistant Professor of Forest Utilization and Assistant Forester in the West Virginia University Agricultural Experiment Station; and W. H. Reid, Associate Professor of Forest Utilization and Associate Forester in the West Virginia University Agricultural Experiment Station.

Cover photograph shows miners driving wooden pin in borehole for roof reinforcement in a West Virginia coal mine.

Courtesy of the Bureau of Mines, U. S. Department of the Interior.

WEST VIRGINIA UNIVERSITY
AGRICULTURAL EXPERIMENT STATION
COLLEGE OF AGRICULTURE, FORESTRY, AND HOME ECONOMICS
A. H. VANLANDINGHAM, ACTING DIRECTOR
MORGANTOWN

Wedge Fastenings For Wood Mine Pins

C. B. KOCH and W. H. REID

Introduction

THE technique of rock bolting as a means of rock support in mines has developed rapidly since World War II (2, 10, 11). A basically different principle is involved in roof bolting as contrasted to conventional timbering. Successful bolting depends upon being able to make the ground itself an integral part of the support structure, whereas with conventional timbering, it is assumed that ground failure is inevitable and effort is made to support it within certain limits.

The practice of roof bolting was initiated more than 25 years ago by the St. Joseph Mining Company of Missouri (1). Since then it has been shown to be practical in underground mining from both the standpoints of safety and economy (2, 5, 6, 9, 10). The use of steel bolts for rock control is increasing. It is estimated that 3,000,000 steel bolts per month were installed in coal mines, and 1,000,000 bolts per month in non-coal nines during 1955. In 1956 there was an estimated 20 per cent increase ver 1955 in the number of bolts installed in coal mines (12).

Wood pins for mine roof control have been utilized with success by he Norton Coal Company in western Kentucky (4) and by the Day Mines n the Northwest (3, 7). They have been found to be economical as to ma-erial and installation costs, and they appear to be especially effective here corrosive water-borne chemicals preclude the use of steel olts (4).

There is the possibility that in many other areas the use of wood ins for rock control would result in reduced material costs and free for ther uses at least part of the estimated 120,000 tons of steel now used nnually for roof support.

It was the purpose of these tests to determine the holding capacity nd resultant displacement of wood pins using different size pins and edges and to evaluate the factors affecting holding capacity so that the ost suitable design might be developed.

Experimental Procedure

Testing technique: A previous report discusses in detail the testing apparatus and method used in testing the wood pins (8). The holding device, which was designed to simulate the rock portion of an actual mine roof, consisted essentially of a concrete cylinder 8 inches in diameter and 14 inches long encased in a steel form (see Figure 1). A hole of the desired size was cast in the cylinder prior to the setting of the concrete. The pins were driven into the cylinder to the maximum depth possible without obtaining excessive pin crushing. After a pin was inserted in the holding device, the assembly was placed in a universal testing machine and a tensile load was applied parallel to the length of the pin. Load and displacement values were recorded simultaneously at each 500-pound load increase until the maximum load was obtained. In some tests additional displacement values were obtained up to the point where the pins were completely removed.

Description of pins tested: Inasmuch as hickory *(Carya* spp.) has somewhat higher strength properties than most other native woods and is available in considerable quantities, it was selected for the manufacture of the pins. The average specific gravity of the pins tested was 0.63 based on green volume and oven-dry weight. They were manufactured on a dowel machine while green, end coated, and subsequently dried to a moisture content of between 10 and 12 per cent before testing. Only pins with no noticeable strength-reducing defects were used.

Description of fastening device: Numerous types of fastening devices have been used to anchor wood pins in mine roofs. Some of these which have been manufactured, at least in limited quantities, make use of metal attachments, but to date there is no information available as to their effectiveness. The type most commonly used at present and the one with which this report is concerned consists of a slot and wedge. The slot, which is sawed along the grain of the pin, is fitted with a wood wedge and inserted in the hole in the roof (see cover picture and Figure 2) or, in these tests, the holding device. When the butt end of the wedge comes in contact with the end of the hole, further penetration results in the wood being forced outward against the wall of the hole. The primary factor involved in the holding ability of such a device is presumably the amount of friction developed between the wood and the holding medium which is dependent on the force of contact, contact area, and coefficient of friction.

In this experiment the slots used were 3/16 inch wide and 3 inches longer than the wedges used. During seasoning the pins shrank a greater amount tangentially than radially, the result being that the cross-sections

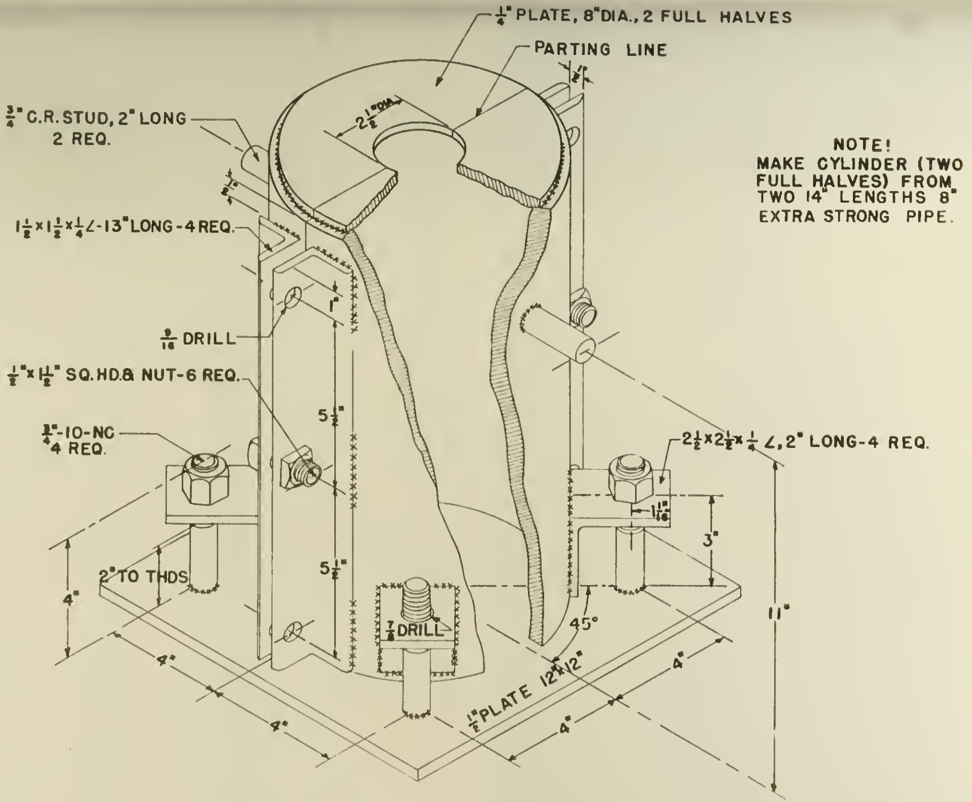

Figure 1. Steel form used to encase concrete test cylinder.

Figure 2. Suspension timbering using wood mine pins and cross-headers. Courtesy of U.S. Bureau of Mines

at time of test were more or less elliptical rather than circular. The slots were cut along the growth rings, the line of cut corresponding to the minor axis of the ellipse. The wedges used conformed to the sketch shown in Figure 3, the slope of such a wedge being $\frac{t - b}{2 \times l}$.

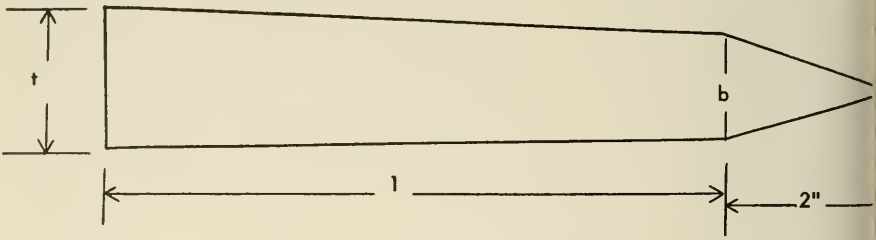

Figure 3. Diagram of wedge used in tests of wood pins.

Results of Tests

Pin-hole-wedge size relationships: In this phase of the experiment tests were made to determine the relative efficiencies of fastenings using vedges of different sizes for holes with diameters of 1 3/4 inches and 1 7/8 inches. The wedges were manufactured from red maple *(Acer rubrum* L.) with an average specific gravity based on oven-dry weight and green volume of 0.46. The wedge sizes used are shown in Table 1. The diameters of the pins used were 1 5/8 inches at the time of test.

Table 1. Wedge sizes used in tests to determine effect of length and thickness on holding capacity.

Diameter	Hole Length (l)*					
	6"		8"		10"	
	t*	b*	t	b	t	b
1 3/4"	6/16"	5/16"	6/16"	5/16"	6/16"	5/16"
	7/16"	6/16"	7/16"	6/16"	7/16"	6/16"
	8/16"	7/16"	8/16"	7/16"	8/16"	7/16"
1 7/8"	8/16"	7/16"	8/16"	7/16"	8/16"	7/16"
	9/16"	8/16"	9/16"	8/16"	9/16"	8/16"
	10/16"	9/16"	10/16"	9/16"	10/16"	9/16"

*See Figure 3.

Five tests were made for each wedge size; the pin used in each test as selected at random from the entire group. No concrete test cylinder as used for more than five tests, and in cases where cylinders split or owed signs of fracture, they were discarded.

The results of the tests are shown in Table 2, and the analysis of riance in Table 3.

It will be noted that no data are included for holes having diameters 1 7/8 inches. This is due to the fact that it was impossible to drive ns in this size hole without splitting them longitudinally during wedge ertion or during the early stages of driving. Consequently, it appears ident that a difference of 1/4 inch between pin and hole diameter is too eat, at least for the length of slot used here.

Effect of slope on holding capacity: As indicated in Table 1, the ference between t and b for each wedge was constant (1/16 inch). Varions in slope were therefore inversely proportioned to variations in

Table 2. Mean values of maximum load, displacement and wedge penetration for 1 5/8-inch diameter hickory pins using different wedge slopes.

	Group A			Group B			Group C		
Wedge Thickness	t=6/16''; b=5/16''			t=7/16''; b=6/16''			t=8/16''; b=7/16''		
Length	6''	8''	10''	6''	8''	10''	6''	8''	10''
Slope	1/192	1/256	1/320	1/192	1/256	1/320	1/192	1/256	1/320
Maximum load (lbs.)	2800	4500	4700	7200	7100	6600	8200	7100	6700
Displacement (in.)	0.035	0.060	0.080	0.116	0.106	0.100	0.130	0.122	0.170
Penetration* (in.)	5.2	7.5	7.9	5.7	5.1	5.4	4.6	3.7	4.6

*This refers to depth that wedge entered slot.

Table 3. Analysis of variance of holding capacity where wedge thickness and slope are varied, t-b being constant.

Source	Degrees of freedom	Sums of Squares	Mean Squares	F
Slope (length)	2	433,333	216,667	0.142
Thickness	2	100,233,333	50,116,667	32.76**
Slope X Thickness	4	17,533,334	4,383,333	2.86 *
Error	36	55,090,000	1,530,218	
Total	44	173,290,000		

**Highly significant.
*Significant.

length. The F value of 0.142 (Table 3) indicates that variance due to differences in slope is insignificant and could be attributed to chance rather than to different populations. This lack of variance can probably be attributed largely to the fact that differences in the slopes were small. Also, the average penetration of the wedges into the slots was about the same for all three slopes so that, for lengths of 8 and 10 inches, a considerable portion of the wedge was not utilized.

In tests for the significance of differences between means within slopes, it was found that the means for Group A differed significantly from those for corresponding slopes in Groups B and C, but that there was no significant difference between means for corresponding slopes within Groups B and C. This is further evidenced by reference to Table 2 which shows that, within a slope, increased thickness from Group A to Group B resulted in considerable increase in holding capacity, whereas change from Group B to Group C was small. The marked increase in holding capacity obtained by increasing thickness from 3/8 inch to 7/16 inch is probably the result of more wood in compression with consequent increase in friction.

Effect of wedge thickness on holding capacity: Each of the three Groups listed in Table 2 represents an individual wedge thickness. The F value of 32.76 (Table 3) indicates that variation in holding capacity due to differences in wedge thickness is highly significant. Figure 4 represents the relationship graphically. The individual points on the curve are averages of holding capacity values for the three different thicknesses tested. It is evident from the curve (curve A) that the greatest increase in holding capacity resulted from increasing the wedge thickness from 3/8 inch to 7/16 inch; a lesser increase was obtained by increasing thickness from 7/16 inch to 1/2 inch. Presumably, had progressively thicker wedges been used, the curve would eventually slope downward to the right since a point would be reached where it would be impossible to drive the pins. Had the minimum thickness been 3/16 inch or less, no holding effect could have been expected since the wedges would have merely filled the slots in the pins.

Differences between means within a particular thickness are significant only in the case of wedges with a thickness of 3/8 inch (Group A). The differences encountered here can be largely attributed to greater penetration for the longer wedges with consequent increase in compression of the wood in the hole. For thicknesses of 7/16 inch and 1/2 inch Groups B and C), the variation in holding capacity due to differences in slope was small as were differences in penetrations for the different engths. This would indicate that the use of wedge lengths in excess of 6 inches offers no advantage unless the wedges are thin enough so that

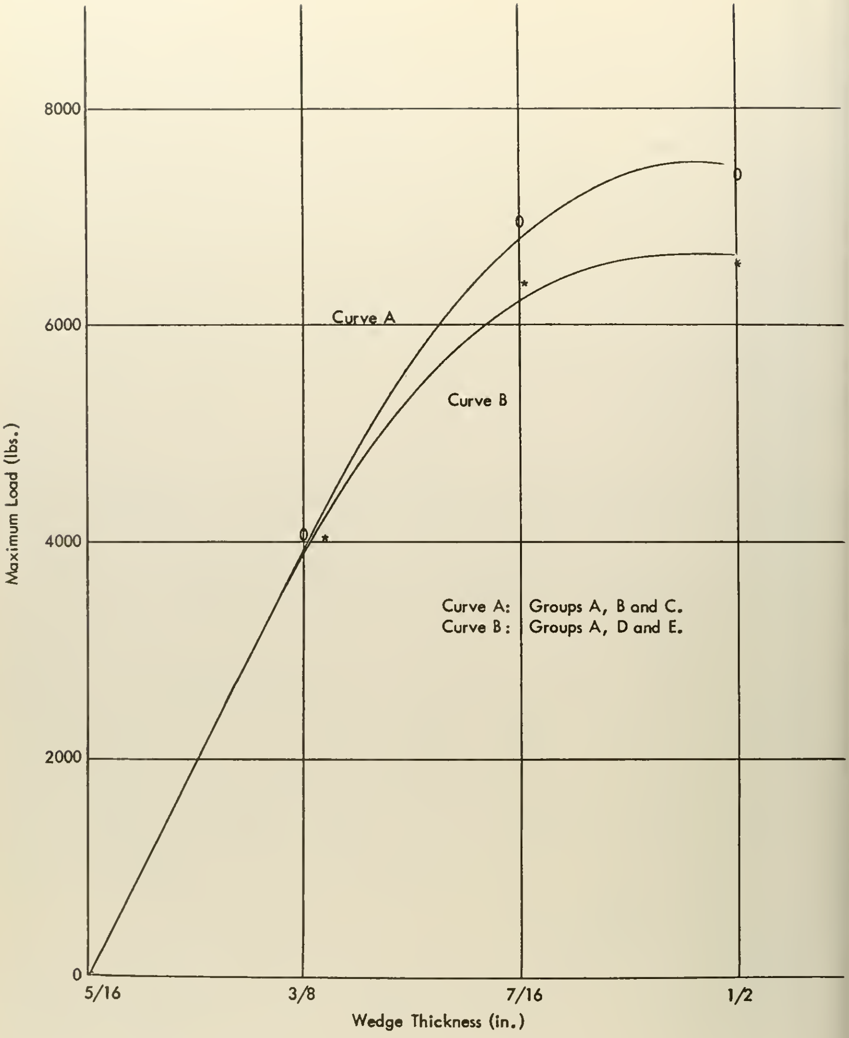

Figure 4. Relation between holding capacity and wedge thickness.

additional length results in greater penetration. In fact, the use of the longer wedges in Groups B and C resulted in considerable damage to both pins and wedges during driving, a factor which may account for the decreases in holding capacity encountered.

Table 4 gives the results of further tests to analyse the effect of slope and thickness on holding capacity. An analysis of variance is given in Table 5.

The wedges used here had b dimensions of 5/16 inches in all cases. This dimension was just sufficient to bring the pin against the holding medium at the beginning of penetration. Tests were made using wedges with lengths of 6, 8 and 10 inches for each thickness (t dimension), but with thicknesses of 7/16 inch and 1/2 inch, wedges 10 inches in length crumpled severly in driving. Consequently, data on wedges of this size were not included in the analysis of variance.

In all, results of tests using seven different treatments were analyzed. Each treatment consisted of a different slope, the differences in slope being obtained by varying thickness and length. Differences in slope between thicknesses were considerably greater than differences in slope within thicknesses. The F values in Table 5 indicate that a highly significant variation in holding capacity means resulted from the use of seven treatments, the major part of the variation being attributable to ifferences in thickness.

As shown by Table 4 the mean values are considerably higher for wedges with thicknesses of 7/16 inch and 1/2 inch (Groups D and E) han for those with thicknesses of 3/8 inch (Group A), the differences beng highly significant. There is no significant difference between means within Groups D and E nor is there any significant difference in means or corresponding lengths between the two groups. Figure 4 (curve B) repesents graphically the relation between thickness and holding capacity. t appears that the effect of thickness here was similar to that discussed previously, the increase in holding capacity occasioned by greater wedge hickness being somewhat less, due probably to the reduced b dimension.

Effect of pin diameter on holding capacity: In order to investigate he effect of pin diameter on holding capacity, tests were made using pins with diameters of 1 3/8 inches, 1 1/2 inches and 1 5/8 inches; the hole iameter in each case was 1/8 inch greater than the pin diameter. Wedges were made of hickory rather than maple and were 6 inches in length.

Initial tests were made with wedges having a t dimension of 1/2 nch, a slope of 1/192, and a length of 6 inches, since this size wedge ppeared to be the most effective in previous tests (see Table 1, Group). It was found, however, that with this size hickory wedge the peneations obtained were considerably less than when maple wedges were

Table 4. Mean values for maximum load, displacement and wedge penetration for 1 5/8-inches diameter hickory pins where wedge slope is varied by changes in both length and thickness.

	Group A			Group D			Group E		
Wedge Thickness	t=6/16''; b=5/16''			t=7/16''; b=5/16''			t=8/16''; b=5/16''		
Length	6''	8''	10''	6''	8''	10''	6''	8''	10''
Slope	1/192	1/256	1/320	1/96	1/128		1/64	3/256	
Maximum load (lbs.)	2800	4500	4700	5900	6700		6000	7100	
Displacement (in.)	0.035	0.060	0.080	0.106	0.103		0.109	0.117	
Penetration* (in.)	5.2	7.5	7.9	5.6	7.1		6.0	6.6	

*This refers to depth that wedge entered slot.

Table 5. Analysis of variance of holding capacity where wedge thickness and slope are varied, b being constant.

Source	Degrees of freedom	Sums of Squares	Mean Squares	F
Treatment	6	66,242,857	11,040,476	8.43**
(Thickness)	(2)	(50,717,857)	25,358,928	19.36**
(Remainder)	(4)	(15,525,000)	3,881,250	2.96*
Error	28	36,670,000	1,309,643	
Total	34	102,912,857		

*Significant.

**Highly significant

used due to the fact that the maple was compressed to a greater extent. Consequently, further tests were made using wedges with the same slope but with the t dimension reduced to 7/16 inch to allow more complete penetration. Results of tests shown in Table 6 and the analysis of variance in Table 7.

As shown by Table 6, the general effect of increased diameter was an increase in holding capacity; the increases, though not statistically significant, are approximately what would be expected on the assumption that holding capacity is proportional to contact area - i.e., diameter.

Variation in holding capacity due to differences in wedge thickness was highly significant (Table 7). The higher values obtained from use of the thinner wedges can be attributed largely to increased penetration and to the fact that damage to the wood during driving was less.

A comparison of the holding capacities obtained by using hickory and maple wedges indicates that the optimum thickness is somewhat less for hickory, probably because of its greater compressive strength perpendicular to the grain.

For the same size wedges and pins, the average holding capacity with maple wedges was 7,700 lbs. compared to 9,000 lbs. with hickory wedges, the difference being statistically significant.

Effect of perservative treatment on holding capacity: In order to determine the effect of perservative treatment on holding capacity, tests were made using creosote treated pins and wedges. Both the pins and the wedges were pressure treated, the average absorption per pin being about 12 pounds per cubic foot. Pin and hole diameters were 1 5/8 inches and 1 3/4 inches respectively. The two wedge sizes used were the same as those described previously (see Table 6), the untreated pins serving as controls. The results of the tests of the treated pins and the controls are compared in Table 8.

As shown in this table, the use of preservative treatment resulted in increased holding capacity when the larger wedges were used and a reduction when the smaller ones were used. The differences were significant for both sizes. The use of the larger treated wedges resulted in significantly higher average holding capacity; the reverse was true for the controls.

The preservative treated pins were easier to drive than the controls, resulting in complete penetration for both wedge sizes. In the case of the controls only partial penetration was obtained. Presumably, the increase in holding capacity obtained by use of the larger preservative treated wedges over that obtained with the controls was due to increased contact area between the pins and holes. The increase in contact area when the smaller treated wedges were used was less marked, and the ease of driving indicated that compression of the wood was slight.

Table 6. Mean values for maximum load, displacement and penetration for pins with different diameters using hickory wedges.

Pin diameter	1-3/8"		1-1/2"		1-5/8"	
Wedge dimensions	7/16" x 6/16"*	1/2" x 7/16"	7/16" x 6/16"	1/2" x 7/16"	7/16" x 6/16"	1/2" x 7/16"
Maximum load (lbs.)	8800	7500	9500	7800	9400	8800
Displacement (in.)	0.140	0.134	0.125	0.134	0.120	0.137
Penetration (in.)	5.1	2.4	3.8	1.9	3.6	

*The t and b dimensions, respectively.

Table 7. Analysis of variance of holding capacity where pin diameter is varied.

Source	Degrees of freedom	Sums of Squares	Mean Squares	F
Diameter	2	3,266,667	1,633,333	1.23
Thickness	1	12,675,000	12,657,000	9.65**
Diameter x thickness	2	800,000	400,000	0.30
Wedges	24	31,800,000	1,325,000	
Total	29	48,541,667		

**Highly significant.

Table 8. Comparison of results of tests of treated and untreated pins.

Wedge Size	b=7/16"; t=8/16"		b=3/8" t=8/16"	
Treatment	Treated	Untreated	Treated	Untreated
Maximum load (lbs)	11,100	8800	7300	9400
Displacement (in.)	0.098	0.141	0.089	0.120
Penetration (in.)	6.0		6.0	3.6

From the previous discussion it would appear that an increase in wedge size is desirable when preservative treatment is used, provided that the increase is not so great that adequate penetration cannot be obtained. The results also indicate that, for comparable size treated and untreated pins and wedges, the treatment results in increased holding capacity if sufficient compression is obtained.

Relation between load and displacement: In general, displacement values for a given treatment showed considerably greater variation than load values. For the 13 different treatments using maple wedges, the average coefficient of variation for the load values was 18.0 per cent, as compared to 31.0 per cent for the displacement values. For the 6 treatments using hickory wedges (see Table 6), comparable values were 12.9 per cent and 23.2 per cent respectively.

There are several probable causes for the greater variation in displacement values. In the first place, many of the pins used were warped to some extent. During the loading process, a considerable part of the recorded displacement was accounted for in straightening the pins. Also, in some cases it was impossible to drive the pins exactly parallel to the longitudinal axes of the holes; thus some straightening of the pins occurred prior to actual slippage. In cases where pins split during removal, abnormal displacement values were also obtained. Variation in pin density, with consequent variation in modulus of elasticity was probably another contributing factor.

Correlation coefficients between load and displacement for 13 treatments using maple wedges and 6 treatments using hickory wedges were calculated and tested for significance. Of the 19 coefficients, only one proved to be significant, a fact which indicates that, within the treatments used, correlation between load and displacement was slight.

However, when the mean load and displacement values for the treatments using maple wedges were plotted, a considerably higher correlation was evident, as shown in Figure 5. The coefficient of correlation is

+ 0.851, which is highly significant. The standard error of estimate, as indicated in Figure 5, is + 0.008. This is the square root of the mean square of the errors of estimate, and its magnitude would indicate a linear relationship in this case. The square of the correlation coefficient (coefficient of determination) is 0.722, indicating that approximately 72 per cent of the variation in displacement was due to variation in load.

In order to investigate further the relation between variation in treatment and displacement where maple wedges were used, an analysis of variance of displacement was made. Results are shown in Table 9. The F value of 5.00 obtained by dividing the variance between treatments by the variance within treatments indicates that variation in displacement means between treatments is highly significant.

Table 9. Analysis of variance of displacement means for treatments using maple wedges.

Source	Degrees of freedom	Sums of Squares	Mean Squares	F
Between	12	0.066	0.0055	5.00**
Within	52	0.058	0.0011	
Total	64	0.124		

**Highly significant.

An analysis of the relationship between mean load and displacement values obtained from tests using hickory wedges indicates that the increased holding capacity resulting from increasing pin diameter did not result in corresponding increases in displacement. For the larger size wedges used (see Table 6), the displacement means were practically constant regardless of load. The displacement values obtained when the smaller wedges were used decreased slightly as the loads increased.

Undoubtedly a considerable portion of the measured displacements resulted from elongation of the pins themselves. Assuming a modulus of elasticity of 2,000,000 pounds per square inch for hickory in tension parallel to the grain, this elongation would amount to something in excess of 50 per cent of the total displacement. For a given pin size, the displacement would be proportional to the load, resulting in a positive regression coefficient as shown in Figure 2. In the case of the tests where untreated hickory wedges were used, however, the increased loads were accompanied by more or less proportional increases in cross-sectional area. Elongation, being proportional to load and inversely proportional to area, would therefore be expected to remain constant.

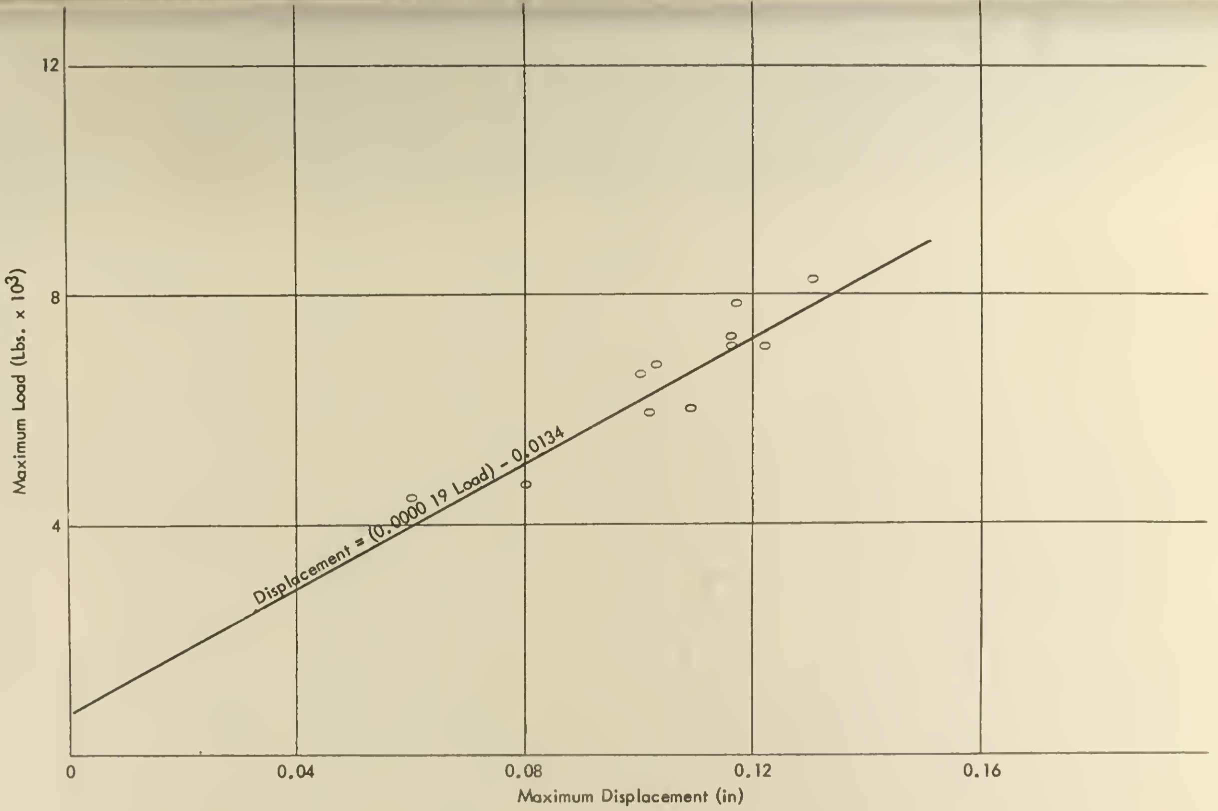

Figure 5. Relationship between maximum load and displacement using maple wedges.

Figure 6 shows a representative load-displacement diagram for an individual test. In general, the diagrams obtained from the other tests are similar and exhibit the following properties:

a. The curves consist of two essentially linear sections of approximately equal slope, indicating zones of proportionality between load and displacement. The two linear sections are separated by a line of lesser slope, the reduced slope occurring between loads of 3,000 and 4,000 pounds, involving a displacement of between 0.02 inch and 0.03 inch.

b. The average slope of the curves (the ratio of maximum load to displacement at maximum load) was practically the same for all tests.

After the maximum load was reached, further displacement was accomplished with decreasing load until complete removal occurred. In most cases the reduction in load was not uniform but occurred in "jumps" the pins appearing to hold until the load built up to a certain point and then slipping suddenly. The frequency of the jumps increased as the pins were removed.

In a test of the type used here, total displacement is necessarily the sum of the elongation of the pin and the slippage occurring between the pin and the holding medium. Inasmuch as none of the loads obtained was of sufficient magnitude to stress the pins to the proportional limit in tension parallel to the grain, it would be expected that that portion of the displacement due to elongation of the pins would be directly proportional to load.

The dotted line in Figure 6 represents the approximate relation that would exist between load and pin elongation, assuming a modulus of elasticity of 2,000,000 pounds per square inch in tension parallel to the grain. It will be noted that the slope of this line is not materially different from the average slope of the other curve, provided that the zone of excessive displacement occurring between loads of 3,000 and 4,000 pounds is eliminated. It appears, therefore, that the major portion of displacement occurring prior to the maximum load can be attributed to elongation of the wood.

No definite explanation for the lesser slope of the curves between loads of 3,000 and 4,000 pounds can be given as yet. It is felt that probably either misalignment of the testing device in the machine of some factor in the operation of the machine was responsible.

Conclusions

The conclusions presented here are based on the objectives of this experiment, the primary objective being to determine optimum pin-wedge-hole size relationships for wood mine pins using slot and wedge type fastening devices.

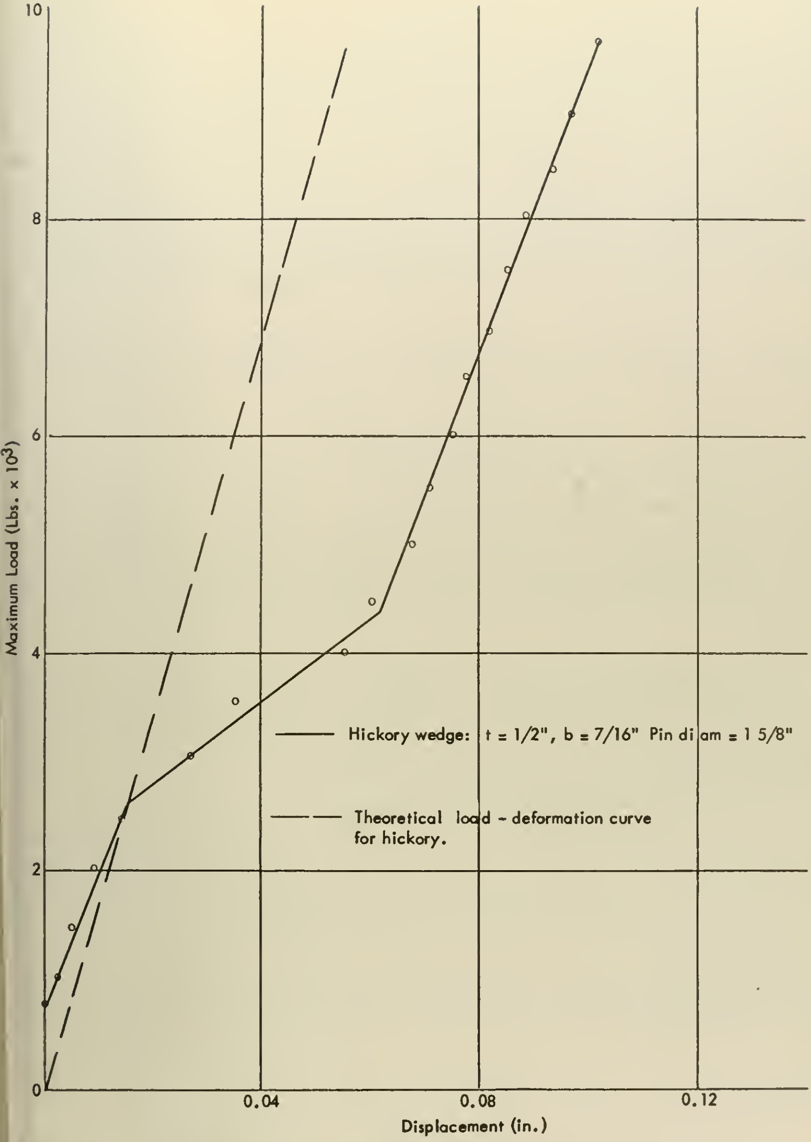

Figure 6. Typical load – displacement diagram.

The major factors affecting holding capacity appear to be wedge thickness and, to a lesser extent, wedge taper or slope. To obtain satisfactory resistance to displacement, the wood in the hole must undergo compression perpendicular to the grain, the amount of compression depending on the thickness of the wedge. Maximum holding capacity values were obtained using wedges of a thickness sufficient to allow 3/16 inch compression where maple was employed and 1/8 inch where hickory was employed. Inasmuch as the difference between pin and hole diameter was 1/8 inch and slot width was 3/16 inch, the most satisfactory thicknesses were 1/2 inch and 7/16 inch for maple and hickory, respectively. It was impossible to drive thicker wedges satisfactorily, and thinner wedges did not offer sufficient compression. The same amount of compression could, of course, be obtained by varying wedge thickness in conjunction with slot width or pin-hole diameter difference. However, the use of thinner wedges in this experiment resulted in considerable crumpling with a consequent decrease in penetration, whereas differences in excess of 1/8 inch between pin diameter and hole diameter resulted in the splitting of the pins during the initial stages of driving. The use of wedges with El dimensions in excess of 6 inches offered no increase in holding capacity except where complete penetration was obtained with thin wedges. Where wedges with thicknesses of 7/16 inch and 1/2 inch were used, the use of wedges longer than 6 inches resulted in significant decreases in holding capacity.

The amount of wood in compression is also dependent on the slope or taper of the wedge. In general, holding capacity is inversely proportional to slope. For both maple and hickory wedges, maximum holding capacity values were obtained when a slope of 1/192 (a taper of 1/1 inch per 6 inches of length) was used.

Increased pin diameter with concomitantly increased hole diameter resulted in increased holding capacity and reduction in displacement The additional holding capacity was approximately proportional to the increase in contact area between the pin and the hole. The largest pins tested had diameters of 1 3/4 inches; the smallest 1 3/8 inches. Besides offering increased holding capacity the larger pins were less easily damaged during driving. It is felt that use of pins larger than those used in this experiment would notbe economically feasible due to increased drilling costs.

Displacement of pins was proportional to load until the maximum load was attained. The major portion of the displacement resulted from elongation of the pin itself-rather than from slipping. Apparently any increase in the efficiency of the wedge from the standpoint of holding capacity will be attended by increased displacement. To reduce the displacement at a given load, either pin diameter must be increased or material with a higher modulus of elasticity must be used.

None of the holding capacity values obtained were of sufficient magnitude to stress the pins beyond the proportional limit in tension parallel to the grain. It is probable, therefore, that the displacement at a particular load would remain constant over a considerable period unless the mechanical properties of the wood were reduced due to changes in moisture content.

Pins treated with creosote behaved similarly to those which were untreated, the only noticeable difference being that slightly thicker wedges were required for comparable results, the increase in thickness presumably compensating for an increase in the plasticity of treated material.

Bibliography

1. Bucky, P. B., "Theory of Roof Bolting" *American Mining Congress Yearbook. Coal Mine Modernization,* pp. 13-18. Philadelphia, 1950.

2. Brown, E. H. and J. Bierner, "Roof Bolting in West Virginia" *Mining Congress Journal,* May, 1951.

3. Farmin, Rollin and C. E. Sparks, "The Use of Wooden Rock Bolts in the Day Mines" Trans. AIME, 196, pp. 922-924, September, 1953.

4. Lanier, S. J., Jr., "Wooden Pins for Mine Roof Control" *American Mining Congress Yearbook. Coal Mine Modernization,* pp. 19-24. Philadelphia, 1950.

5. McLellan, G. B., "Economy of Roof Bolting" *Mining Congress Journal*, September, 1951.

6. Meakin, W. D., "Roof Bolting Benefits Ventilation" *Mining Congress Journal,* January, 1951.

7. Pollish, Lloyd and Robert Breckenridge, "Rock Bolting in Metal Mines of the Northwest" *Mining Engineering,* July, 1954.

8. Reid, W. H. and C. B. Koch, *A Laboratory Method of Testing Wood Mine Pins in Tension.* Bulletin 383T, West Virginia University Agricultural Experiment Station, November, 1955.

9. Stevens, E. H., "Successful Roof Bolting in Alabama" *American Mining Congress Yearbook. Coal Mine Modernization*, pp. 31-39. Philadelphia, 1951.

10. Thomas, E. M., "Roof Bolting to Prevent Accidents" *American Mining Congress Yearbook. Coal Mine Modernization*, pp. 40-43. Philadelphia, 1950.

11. Thomas, E. M., "Rock Bolting Finds Wide Application" *Mining Engineering*, November, 1954.

12. Thomas, E. M., *Personal Correspondence*, November, 1956.

13. Wuerker, R. G., "Testing of Roof Bolting Systems Installed in Concrete Beams" *Mining Engineering*, June, 1953.