# RESPONSE OF TIMBER JOINTS WITH METAL FASTENERS

## TO LATERAL-IMPACT LOADS

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## Abstract

Recent studies at the Forest Products Laboratory were made of two-member wood joints fastened with nails, bolts, or lag screws and subjected to lateral-impact loads. These studies established a relationship, which is independent of the type of metal fastener, between magnitude of impact force, joint slip, fastener diameter, and specific gravity of wood (Douglas -fir) members. Electronic instrumentation was employed to measure and record the instantaneous forces that were applied to joints in both pendulum and drop tests.

Three types of fasteners were tested: Eight-, sixteen-, and thirty-penny nails; 1/4-, 1/2-, and 3/4-inch bolts; and 5/16-, 1/2-, and 3/4-inch lag screws. The work was done in cooperation with the U. S. Air Force, and will be the basis for revised load ratings for metal fasteners in a new blocking and bracing guide under preparation for Air Force use.

## Method

Available design data applicable to wood-member joints that are secured with metal fasteners are based, almost entirely, on results from tests in which

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loads were slowly applied to test joints. When such fasteners *are* used to secure or brace items in shipping containers, however, they are likely to experience severe dynamic forces from impacts that are applied to the container during handling and shipment. At present the number, direction, and severity of impacts that may be experienced by a given shipment can only be estimated, but a preshipment performance test that involves specific impacts may be required for military packages. Because packaged aeronautical equipment, of a size or weight likely to require wood blocking and bracing, may be required to pass the pendulum-impact test of Military Specification MIL-P-7936, that test is the design basis for the pendulum tests reported here. A free-fall drop test was also used that was simpler in some respects than the pendulum test. The tests employed mostly the 9-inch drop height specified in MIL-P-7936; however, in a series of check tests with sixteenpenny nails, the drop height was varied between 4 and 30 inches.

Test joints consisted of a main member of nominal 4- by 4-inch size and a shorter cleat, 1 by 4 or 2 by 4 inches, which was fastened to the main member.

All wood used was Douglas -fir, except that white fir was used for cleats with the eightpenny nails. The mean specific gravity of the Douglas-fir material was 0.459 with a standard deviation of 0.055. The white fir mean was 0.361 with a standard deviation of 0.026. Moisture content ranged from 12 to 18 percent.

In one series, which involved all 12 kinds and sizes of fasteners, grain direction in the two wood members was parallel and coincident with the direction of applied load. In a second series, which involved only the two smaller sizes of each of the three kinds of fasteners, grain directions were mutually perpendicular, and the load was applied to the side grain of the cleat. Recommended fastener spacing, member penetration, and installation techniques were adhered to in preparing all test joints.

The number of fasteners per joint varied from 19 for the pendulum test of eightpenny nails, in which two joints were tested simultaneously, to one fastener per joint for several tests that involved the larger fasteners. In the pendulum tests, all fasteners were tested with a 260-pound cast iron plate as the impact head. Ten-, fifteen-, and twenty-pound impact heads were used for the drop tests. Except for the drop tests with two sixteenpenny nails per joint, the number of fasteners in each test joint was chosen on the basis of exploratory tests to give an anticipated slip of approximately 0.20 inch on the initial impact from a 9-inch fall.

For safety and ease in manual handling, the impact head that was used in the free-fall drop test was limited to a maximum of 20 pounds. This limitation

did not permit loading the larger fasteners to the same extent as in the pendulum-impact tests.

In all impact tests, both the test joint and the impact head were either swung or dropped as a unit, so that a protruding end of the main wood member struck squarely and solidly against either a massive concrete abutment or a steel plate that was embedded level in the top horizontal surface of another large mass of concrete. Sandwiched between the impact head and each test cleat, and in intimate contact with both during each fall, was a resistance strain-gage load cell.

Each test joint was subjected to repeated impacts from the same drop height. The test was terminated (a) when complete separation of the members occurred or was imminent, (b) when several successive impacts produced no residual increase in the accumulated slip, or, (c) as in most of the later tests, after the first three impacts.

In most instances, a given size and type of fastener was tested with four different cleats, each cleat fastened to a different face of the same main member. Where it was necessary to assure full-length bearing against solid wood for all fasteners in the joint, succeeding cleats were shifted lengthwise of the main member.

The residual accumulated slip in the joint was measured after each impact. A force-time display, or in the pendulum tests two simultaneous displays, by a dual-beam oscilloscope was photographed for each of at least the first three impacts, except in infrequent instances of picture failure.

The force-time displays consisted of a fundamental wave, or pulse, of 5 to 20 milliseconds duration, and oscillations of considerably higher frequency, which were superimposed on the pulse. Rough calculations of natural frequencies indicated that elastic stress waves set up by the impact in the various members of the test assembly may have been responsible for the oscillations. While these higher frequency components may have had some effect on the overall behavior of the test joint, there is considerable precedent for ignoring them. Therefore, the values of dynamic force that were used in the analysis of data correspond to peak values of the main force-time pulse obtained by visual readings that disregarded the higher frequency oscillations.

Making such readings of the pictures from the pendulum-impact tests (fig. 1) was not difficult, but this was not true for some of the pictures from the drop tests. In the pendulum tests, because the heavy (260-pound) impact head generated fundamental pulse amplitudes at least several times greater than the amplitude of the superimposed oscillations, the oscillations often resulted in only a comparatively minor vertical widening of the trace. However,

because the drop test involved much lighter impact heads and fewer fasteners per test joint, the amplitude of the main pulse that was generated in this test sometimes was little or no greater than that of the superimposed oscillations (see upper trace in each of the pictures in fig. 2).  This made accurate measurement of the main pulse extremely difficult.  In the later drop tests, both channels of the oscilloscope were utilized; one displayed the signal after passing through a filter that eliminated all components above 2,000 cycles per second and was easily read, and the other displayed the unfiltered signal (fig. 2) and retained all of the force-time information for possible future reference.

## Equipment and Instrumentation

The equipment used for the pendulum tests is shown in figure 3.  A heavy, rigid structural steel framework that was securely anchored to solid concrete piers provided overhead anchorage for four aircraft cables 20 feet long. These cables supported, at its four corners, a pendulum platform of welded steel construction.  The precise leveling and symmetrical alinement of cable attachment points contributed to the steady, true swing of the platform.

The platform surface was galvanized sheet iron over plywood.  The forward edge of the platform, at rest, was parallel to and about 8 inches from the adjacent vertical face of the massive concrete bumper.  A half-round strip of resilient polyurethane foam was glued to the forward edge to cushion impacts between platform and bumper.  On the longitudinal centerline of the platform, at its rear edge, a ring was provided for engagement of the quick-release clevis on the pulling cable.

The pulling cable passed through a pulley that was attached to an anchor post on the extended centerline, and was connected to the hook of an overhead electric hoist.

Two test members, each 8 feet long and cut from the same 16-foot nominal 4- by 4-inch timber, rested on the platform.  These members were similarly oriented on the platform with respect to direction of their growth rings. Their inner edges were positioned parallel to and 10 inches from the platform centerline, and their leading ends overhung the forward edge of the platform to just contact the bumper face with the platform in the rest position.  Provision was made for locking the platform in the rest position.

The test cleats, 1 by 4 or 2 by 4 inches, were attached to the top faces of the 4 by 4's, and 8 inches from the leading ends.  Also attached, by wood screws, to each top face near the leading end was a small reference block for the slip

measurements.  A dial micrometer compression gage, together with precision steel gage blocks when needed, was inserted between the reference block and the end of the cleat to measure joint slip after each impact.

A cast iron rectangular plate that weighed 260 pounds rested on the two 4 by 4's, and was properly centered.[3]  Between the plate and the adjacent end of each test cleat, in intimate contact with both, was one of the two strain-gage load cells (fig. 5).  Each of these transducers weighed 0.85 pound and con- sisted of a solid aluminum alloy block 3 by 3-5/8 by 3/4 inches to which four SR-4, type A-1  strain gages were cemented.  The two active gages on each block were oriented parallel to the 3-inch dimension on opposite 3/4- by 3- inch faces.  The other two gages, oriented perpendicular to the first pair, were cemented side by side to one of the 3- by 3-5/8-inch surfaces. The gages formed the four legs of a resistance bridge circuit that was connected by shielded cable, through a calibration box, to the input terminal of one of the two channels of the dual-beam oscilloscope.  The other load cell was con- nected similarly, through a second calibration box, to the input terminal of the other channel.  Each load cell was calibrated in a standard testing ma- chine, before and after the tests, by determining the compressive load re- quired for a trace deflection equivalent to that produced by the calibration resistor.  Two horizontal sweep traces, one with and one without the calibra- tion resistor, are displayed on the oscilloscope screen along with each impact record.

Sweep synchronization was achieved through an external 3-volt direct current circuit that used a trigger switch composed of two short lengths of flexible steel strapping.  One strap was attached to and extended upward from the leading edge of the pendulum platform. The other strap rested, in part, on the backs top abutment,  and was held there by a weight on one end.   The other end protruded toward the first strap and contacted it near its free upper end when the pendulum was in rest position.  Before each impact, the straps were adjusted so they would make contact 3/4 inch in advance of the impact.

A Land process camera and attachment for the oscilloscope were used to photograph the transient displays.

The setup for the free-fall drop tests (fig. 6) involved single, rather than paired, joints.  The main member was a nominal 4 by 4, 40 inches long. A

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[3]In the later pendulum tests with thirtypenny nails, 3/4-inch bolts, and 3/4- inch lag screws, the iron plate rested on rollers (fig. 4). These minimized any effect of friction,  between plate and 4 by 4's and between the latter and the platform, that may have been a factor in preceeding tests. This required some restraint to hold the various components together and in position on the platform during the swing.

thinner and much shorter member (cleat) was fastened to one side of the main member.  A small reference block for slip measurements was fastened to the same side of the main member about 8 inches from the cleat.  One of the two load cells used in the pendulum tests was positioned against both the main member and the opposite side or end of the cleat from the slip reference block. The impact head, a 2- by 4-inch steel bar, was positioned against the load cell, opposite the cleat.  One or two steel straps, whose ends were fastened to opposite sides of the main member, loosely encircled the impact head on three sides to prevent undue lateral shifting of the bar during the drop test.

The test assembly was suspended by an overhead electric hoist at the desired height, vertically above the dropping surface. The electric hoist cable was equipped with a solenoid-operated release with opposing hinged jaws.  This release applied no lateral force to the suspended item during disengagement. Vertical alinement of the test assembly was checked with a carpenter's level and necessary adjustments were made in the suspension rigging clamped to the upper end of the main member.

The dropping surface was a heavy steel plate embedded flush with the top surface of a large concrete mass that formed part of the ground-level concrete floor, as well as extended well below it.  This steel plate formed one terminal of the trigger in the external sweep synchronization circuit.  The other terminal was a short length of bare copper wire that was fastened to the side of the main member, near its impact end,  and was bent to contact the steel plate 1/4 inch in advance of impact.

Because of the much lower impact forces that were generated in the drop tests than in the pendulum tests, additional amplification of the signal pulse, in the drop test, was necessary.  Therefore, a direct current preamplifier set at a gain of 250 times was connected between the calibration box and the oscilloscope.  The signal was fed directly to one channel through a low-pass filter with a cut-off frequency of 2,000 cycles per second.

Slip measurement equipment and procedures were the same for the drop test as for the pendulum test.

Moisture content (ovendry basis) and specific gravity were determined from sections taken adjacent to one end of each test member, using customary procedures.

### Presentation, Analysis, and Discussion of Results

The method used to analyze the data developed from the following relationships. About halfway through the testing program a strong relationship became apparent between dynamic load, $\underline{P}$, which is applied to a joint, and the square root of the resulting slip $(S^{1/2})$. Previous studies at the U.S. Forest Products Laboratory that involved lateral displacement of nails under slowly applied load have indicated a direct relationship between nail diameter raised to the three -halves power $(D^{3/2})$ and load,[4] and also between specific gravity to the three-halves power $(G^{3/2})$ and load.[5]

When values of dynamic load versus values of the product $S^{1/2}D^{3/2}G^{3/2}$ for corresponding impacts were plotted to logarithmic scales for all impacts and all fasteners, a reasonably close approximation to a straight line resulted. When the data originating from initial impacts was plotted as one set, and data from the second and third impacts as separate additional sets, the straight-line fit improved.

The data from all the impact tests are summarized in table 1. The first three columns of this table are self-explanatory. Column 4 lists the number of fasteners of a given kind and size that were impacted simultaneously. Each of these figures is the same as the number of fasteners per test cleat in the drop tests, but is twice the number of fasteners per cleat in the pendulum tests, where two cleats were tested simultaneously.

The figures in column 5 are the result of dividing the total restrained weight (impact head plus load cell) by the corresponding figure in column 4.

Column 7 gives values obtained by averaging the dynamic force measurements obtained from the initial impacts against the several similar test joints of a series, and dividing by the number of fasteners per joint. The figures in column 8 are similarly obtained from dynamic force measurements made on second impacts, and the figures in column 9 are from measurements on third impacts. Because either two or four joints that involve a given kind and size of fastener were tested, and because of infrequent failure to obtain a

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[4]U.S. Forest Products Laboratory. Wood Handbook. U.S. Department of Agriculture Handbook No. 72, 528 pp. 1955.

[5]Scholten, J. A. Nail-Holding Properties of Southern Hardwoods. Southern Lumberman 181(2273):208-210, Dec. 15, 1950.

force-time record for a particular impact, the number of impacts represented by each average value in these columns varied from 1 to 4. This number is shown immediately above the corresponding average value, in each instance. l

Values of slip are given in columns 10, 11, and 12, and each value is the average of slip increments developed in the same impacts that are represented in the corresponding average dynamic force value (columns 7, 8, or 9).

The specific gravity of each cleat or main member was assumed to be that of a small transverse section taken adjacent to one end of the member. This is a common procedure, but it does introduce the possibility of some error because of variation of specific gravity along the length of the stock timber. The specific gravity associated with each test joint is the mean of the values for the respective cleat and main member. In some of the later pendulum tests (those for thirtypenny nails, 3/4-inch bolts, and 3/4-inch lag screws), both test members were cut from the same piece, and matching for specific gravity was good. In other tests, the specific gravity matching varied from good to fair, and probably accounted for some variability in test results. The average specific gravity shown in column 13 is the average of the values for the appropriate individual test joints.

Columns 15, 16, and 17 give values of $S^{1/2}(DG)^{3/2}$ that were calculated from the appropriate value of $\underline{S}$ from columns 10, 11, or 12, plus the corresponding values of $\underline{G}$ and $\underline{D}$ from columns 13 and 14.

Column 18 gives values that are products of average dynamic force per fastener ($\underline{F}$) and of average slip ($\underline{S}$) both for initial impacts. These values represent the average energy expenditure, or work done, per fastener in the initial impacts on the test joints of each particular series. Column 19 gives corresponding values for second impacts, and column 20, third impacts.

Column 21 gives the potential energy that is available for doing work on the test joint during one impact, divided by the number of fasteners in the test joint. Each value is the product of the corresponding entries in columns 5 and 6.

In figures 7 through 10, values of dynamic load per fastener from columns 7, 8, and 9 of table 1 are plotted against corresponding values of the term, $S^{1/2}(DG)^{3/2}$, from columns 15, 16, and 17. Data plotted in figure 7 represents initial impacts only, against all the joints tested in the dynamic tests. Similarly, figure 8 represents only second impacts, and figure 9, third impacts, of all joints tested. Figure 10 combines figures 7, 8, and 9, thus giving an overall representation of the first three impacts on all test joints.

A straight line, of slope 1.0 and positioned visually to approximate the mean of the data points, is shown on each of figures 7, 8, and 9. It should be pointed out that the number of individual test fasteners involved in each data point shown in these figures is the product of the appropriate small secondary number given in columns 7, 8, or 9, of table 1, and the corresponding number from column 4. Thus, for instance from the pendulum test, each data point for sixteenpenny-nailed joints loaded parallel to the grain of the cleat represents tests of 4 times 28, or 112 nails; while each data point for sixteenpenny-nailed joints loaded perpendicular to the grain of the cleat represents tests of only eight nails.

The line shown in figure 10 gives considerable weight to the data points for sixteen- and thirtypenny nails, 3/4-inch bolts, and 3/4-inch lag screws, all loaded parallel to the grain of the cleat. Confidence in these data is enhanced by the close grouping of the points that represent each of the three impacts for each of these fasteners. There probably are three main reasons for this. One is that, except for sixteenpenny nails, these were the last fasteners tested in the pendulum tests, after the techniques had been perfected and early "bugs" were corrected. A second reason is improved matching of specific gravity of cleats with that of the main member for tests involving thirtypenny nails, 3/4-inch bolts, and 3/4-inch lag screws. A third reason, which applies particularly to the nails, is that these data points represent tests of comparatively large numbers of individual fasteners, and thus give better estimates of the true mean values.

The equation for the line in figure 10 is as follows:

$$F = 90,000 \, S^{1/2} (DG)^{3/2} \tag{1}$$

in which $F$ equals dynamic force per fastener (pounds); $S$ equals slip produced by force $F$ in one impact (inches); $D$ equals diameter of fastener (inches); and $G$ equals mean specific gravity of the two wood members (grams per cubic centimeter). The value, 90,000, is the value of $F$ when $S^{1/2}(DG)^{3/2}$ is equal to unity.

In figure 11, values of the product of dynamic load per fastener (pounds) and slip (inches) are plotted against corresponding values of the product of weight of impact head per fastener (pounds) and drop height (inches). A line with a slope of 1.0, and which if extended would pass through the origin is shown. Although considerable scatter above and below this line exists, it does indicate an approximate mean. Further confidence in the relationship indicated by this line is gained by noting its location with respect to the data points representing pendulum-impact tests of joints that involve sixteen- and

thirtypenny nails, 3/4-inch bolts, and 3/4-inch lag screws, all loaded in the grain direction of the cleat.  Reasons for the increased confidence in the data from these particular tests were given previously. The equation of this line is as follows:

$$F S = W h \tag{2}$$

where $\underline{F}$ equals dynamic force per fastener (pounds); $\underline{S}$ equals slip produced by force $\underline{F}$ in one impact (inches); $\underline{W}$ equals weight of impact head plus load cell(s) on a "per fastener" basis (pounds); $\underline{h}$ equals vertical drop height (inches).

Substituting in equation (1) the value $\dfrac{W\,h}{S}$, obtained from equation (2) for $\underline{F}$, and simplifying gives:

$$W = \frac{90,000}{h} (SDG)^{3/2} \tag{3}$$

Thus, we have an equation for two-member joints relating weight restrained per fastener, drop height, slip, diameter of fastener, and specific gravity of wood members.

It should be remembered that for the most part,  $\underline{h}$ in the impact tests was 9 inches, but the relationship expressed by equation (1) was not noticeably affected by drop heights as low as 4 inches and as high as 30 inches (see data points for drop tests of sixteenpenny nails, parallel-to-grain loading, in figs. 7, 8, and 9). However, because the test data for the 30-inch drop height involved only two drops (first and third) of a single two-nail joint, the validity of equation (1) for drops in excess of 18 inches has not been adequately verified.

Because the impact tests involved only two species and involved material of limited range in specific gravity, extrapolation of the data to other species and to other densities may involve some risk.  However, well-established procedures and data for determining allowable lateral-resistance loads for metal fasteners under static conditions indicate that allowable load and specific gravity are quite closely related, regardless of species, throughout the wood density range.  Similar general relationships can be expected to hold under conditions of dynamic loading.

It may be of interest to note that values of allowable lateral-resistance load (static) that were calculated, for nails of various sizes in wood of various species, according to the Wood Handbooks are about double the values of $\underline{W}$ that were obtained for the same species and nail sizes with equation (3), with h = 9 inches and assuming a slip of 0.30 inch.  Data from this study further

indicate that two-member nailed joints loaded according to allowable static values could be expected to slip about 0.50 inch under a single 9-inch impact as applied herein.

Since either a permissible or an assumed value of slip, $\underline{S}$, is required before use can be made of equation (3), some idea of what constitutes a safe value is necessary. Some of the pendulum-impact tests were continued until failure of one of the two cleats, or until terminated arbitrarily after a comparatively large number of repeated impacts. The following tabulation gives the number of impacts to failure and indicates the corresponding total slip:

| Fasteners | Number of impacts to failure | Total slip |
|---|---|---|
| | | (inches) |
| Sixteenpenny nails | 9, 9, 9, 10 | All over 1 inch |
| 1/4-inch bolts | 23+, 14+ | All over 1 inch |
| 5/16-inch lags | 16, 31+ | 1 inch or over |
| 1/2-inch bolts | 8, 7 | 0.7-inch minimum |
| 1/2-inch lags | 8, 9 | All over 1 inch |

The greatest average initial impact slip in table 1, except for the one 30-inch drop test, was roughly 0.30 inch. A slip value of 0.30 appears to be a reasonable starting point for use of equation (3). Lateral-impact load ratings for nails published in Air Force Technical Order T.O. 00-85-8, "Interior Blocking, Bracing, and Cushioning," agree closely with values obtainable by using 0.30 for $\underline{S}$ and 9.0 for $\underline{h}$ in equation (3). As evidence that permits better correlation of package testing with actual shipping experience is developed, it may become desirable to increase the existing lateral-impact load ratings for wood fasteners. A convenient means of doing this in an equitable manner for the various kinds and sizes of fasteners is provided by equation (3).

## Conclusions

A useful and practical method was developed for testing and evaluating the lateral resistance to impact loads for two-member wood lap joints that are secured with metal fasteners.

A comparatively heavy impact head and a correspondingly large number of the fasteners in a test joint were advantageous, particularly when joints with the smaller fasteners were tested. Thus, the magnitude of the total impact force that is to be measured may be increased with respect to the magnitude of the "hash" that usually is present in unfiltered force-time records of impacts on elastic systems.

Two-member wood lap joints secured with nails, bolts, or screws and sub-jected to impact loads that are applied parallel to the plane of contact between the wood members should, for optimum utilization of fasteners, be designed on the basis of permissible slip.

On the basis of their performance when they join two wood (Douglas-fir) mem-bers that are subjected to not more than three impacts, none of which can slide one member with respect to the other more than 0.3 inch, no practical difference exists between nails, bolts, and lag screws of the same diameter.

Table 1.--Dynamic test data for two-member joints secured with various metal fastenings

| (1) Direction of load application with respect to grain of cleat | (2) Kind of fastener | (3) Size of fastener | (4) Number of fasteners per test | (5) Weight of fastener (W) Lb. | (6) Drop height or equivalent head per impact (h) In. | (7) Avg. dynamic force per fastener (F) First impacts Lb. | (8) Second impacts Lb. | (9) Third impacts Lb. | (10) Avg. slip (S) First impacts In. | (11) Second impacts In. | (12) Third impacts In. | (13) Avg. specific gravity (G) per cc. | (14) Diameter of fastener (D) In. | (15) S1/2 (DG)3/2 First impacts | (16) Second impacts | (17) Third impacts | (18) Avg. energy expended per fastener (F x S) First In.-lb. | (19) Second In.-lb. | (20) Third In.-lb. | (21) Avg. potential energy per fastener (W h) In.-lb. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **PENDULUM** | | | | | | | | | | | | | | | | | | | | |
| Parallel | Nail | 8 penny | 38 | 6.90 | 9 | 2 / 356 | 2 / 524 | 2 / 488 | 0.177 | 0.177 | 0.109 | 0.479 | 0.131 | 0.00662 | 0.00549 | 0.00520 | 63.0 | 61.3 | 53.2 | 62.1 |
| Do | do | 16 penny | 28 | 9.36 | 9 | 4 / 645 | 4 / 620 | 4 / 669 | .160 | .123 | .126 | .453 | .162 | .00796 | .00698 | .00706 | 103.2 | 76.2 | 84.3 | 84.2 |
| Do | do | 30 penny | 18 | 14.55 | 9 | 2 / 930 | 2 / 917 | 2 / 971 | .181 | .156 | .140 | .467 | .207 | .0128 | .0019 | .0113 | 168 | 143 | 136 | 131 |
| Do | Bolt | 1/4 inch | 8 | 32.75 | 9 | 2 / 1,791 | 2 / 2,101 | 2 / 2,429 | .297 | .173 | .233 | .388 | .250 | .0165 | .0126 | .0146 | 532 | 363 | 566 | 295 |
| Do | do | 1/2 inch | 4 | 65.50 | 9 | 1 / 4,100 | 2 / 4,415 | 2 / 5,014 | .199 | .230 | .095 | .507 | .500 | .0570 | .0613 | .0394 | 816 | 1,015 | 476 | 590 |
| Do | do | 3/4 inch | 2 | 131.0 | 9 | 4 / 6,100 | 3 / 7,100 | 2 / 7,250 | .179 | .165 | .136 | .459 | .750 | .0856 | .0822 | .0799 | 1,092 | 1,172 | 1,131 | 1,179 |
| Do | Lag screw | 5/16 inch | 10 | 26.2 | 9 | 2 / 1,642 | 1 / 2,036 | 1 / 2,289 | .223 | .134 | .116 | .438 | .312 | .0239 | .0185 | .0172 | 366 | 273 | 265 | 236 |
| Do | do | 1/2 inch | 6 | 43.67 | 9 | 1 / 3,731 | 2 / 3,749 | 2 / 3,501 | .150 | .093 | .080 | .462 | .500 | .0431 | .0339 | .0315 | 560 | 349 | 280 | 393 |
| Do | do | 3/4 inch | 2 | 131.0 | 9 | 4 / 5,960 | 4 / 7,100 | 4 / 7,475 | .220 | .174 | .152 | .462 | .750 | .0957 | .0851 | .0795 | 1,310 | 1,235 | 1,132 | 1,179 |
| **DROP** | | | | | | | | | | | | | | | | | | | | |
| Parallel | Nail | 16 penny | 2 | 7.92 | 4 | 3 / 385 | 2 / 457 | 4 / 404 | .081 | .062 | .052 | .413 | .162 | .00493 | .00432 | .00395 | 31.2 | 28.3 | 21.0 | 31.7 |
| Do | do | 16 penny | 2 | 5.42 | 9 | 3 / 400 | 3 / 372 | 3 / 400 | .111 | .101 | .096 | .432 | .162 | .00617 | .00589 | .00574 | 44.4 | 47.7 | 38.4 | 48.8 |
| Do | do | 16 penny | 2 | 7.92 | 9 | 4 / 621 | 4 / 719 | 4 / 662 | .146 | .117 | .115 | .429 | .162 | .00700 | .00637 | .00622 | 90.7 | 84.2 | 76.1 | 71.3 |
| Do | do | 16 penny | 2 | 10.42 | 9 | 4 / 604 | 4 / 512 | 4 / 525 | .189 | .141 | .150 | .405 | .162 | .00732 | .00632 | .00652 | 114.2 | 72.2 | 78.7 | 93.8 |
| Do | do | 16 penny | 2 | 7.92 | 18 | 4 / 925 | 3 / 950 | 4 / 769 | .263 | .202 | .293 | .518 | .162 | .01249 | .01094 | .01318 | 243 | 192 | 225 | 143 |
| Do | do | 16 penny | 2 | 7.92 | 30 | 1 / 1,210 | ........ | 1 / 1,115 | .530 | .602 | .597 | .409 | .162 | .01244 | ........ | .0132 | 641 | ........ | 666 | 233 |
| Perpendicular | do | 8 penny | 3 | 5.28 | 9 | 2 / 360 | 4 / 446 | 4 / 520 | .174 | .095 | .067 | .364 | .131 | .00435 | .00321 | .00270 | 62.6 | 42.4 | 34.8 | 47.5 |
| Do | do | 16 penny | 2 | 7.92 | 9 | 4 / 793 | 2 / 996 | 3 / 710 | .119 | .076 | .072 | .488 | .162 | .00767 | .00613 | .00596 | 94.5 | 75.7 | 51.1 | 71.3 |
| Do | do | 30 penny | 2 | 7.92 | 9 | 4 / 823 | 4 / 790 | 3 / 969 | .082 | .056 | .037 | .441 | .207 | .00790 | .00653 | .00531 | 57.6 | 44.2 | 35.8 | 71.3 |
| Do | Bolt | 1/4 inch | 1 | 20.85 | 9 | 4 / 1,213 | 4 / 1,240 | 4 / 1,540 | .223 | .114 | .085 | .447 | .250 | .01766 | .01263 | .01091 | 271 | 141 | 131 | 188 |
| Do | do | 1/2 inch | 1 | 20.85 | 9 | 3 / 3,540 | 4 / 3,235 | 4 / 3,140 | .081 | .022 | .025 | .488 | .500 | .0361 | .01866 | .0205 | 287 | 71.2 | 78.5 | 188 |
| Do | Lag screw | 5/16 inch | 1 | 20.85 | 9 | 4 / 1,540 | 4 / 1,618 | 4 / 1,707 | .129 | .076 | .057 | .452 | .312 | .01905 | .0146 | .01265 | 199 | 123 | 97 | 188 |
| Do | do | 1/2 inch | 1 | 20.85 | 9 | 4 / 1,733 | 2 / 2,137 | 4 / 2,090 | .096 | .059 | .062 | .460 | .500 | .0325 | .0255 | .0261 | 166 | 126 | 130 | 188 |

[1] Also the number of fasteners per test cleat, except that for pendulum tests the number shown is double the number per cleat.

[2] The upper figure in each space gives the number of initial, second, or third impacts, respectively, represented by the average (lower) figure.

[3] The values shown are averages of slip measurements for the same impacts represented in the corresponding dynamic force column.
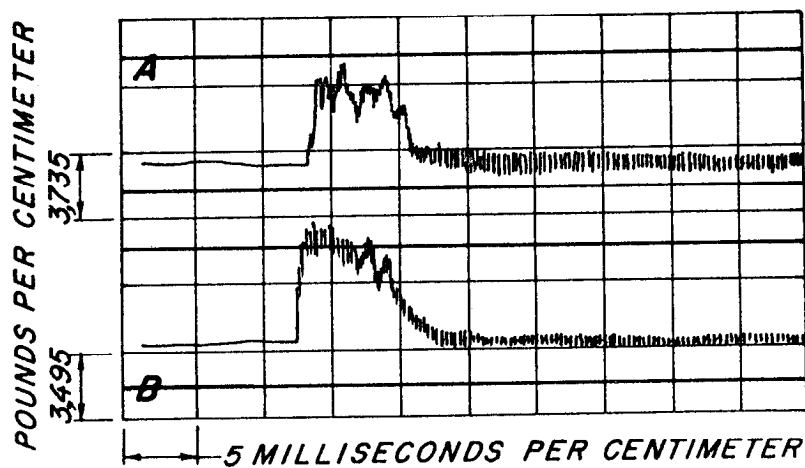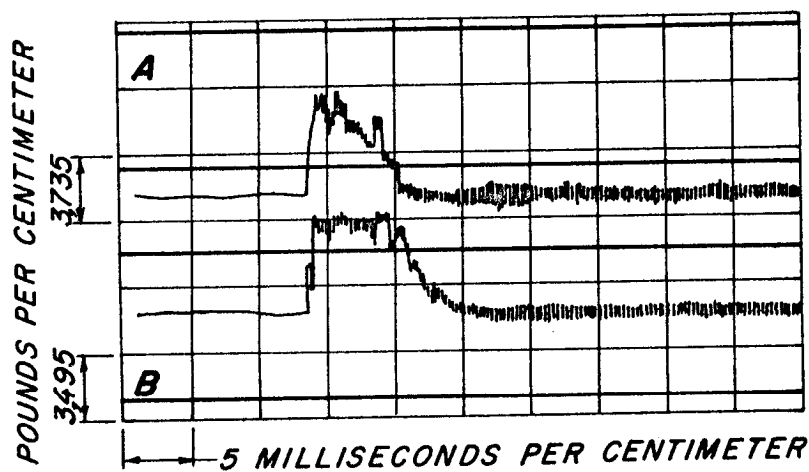
Figure 1. --Drawings of oscilloscope screen showing channels A and B,
which contain typical, paired force-time pulses for pendulum impact
tests of two-member wood joints loaded to produce slip along the plane
of contact between the wood members. The pulses show the initial
impact against the end grain of two pairs of cleats secured with one
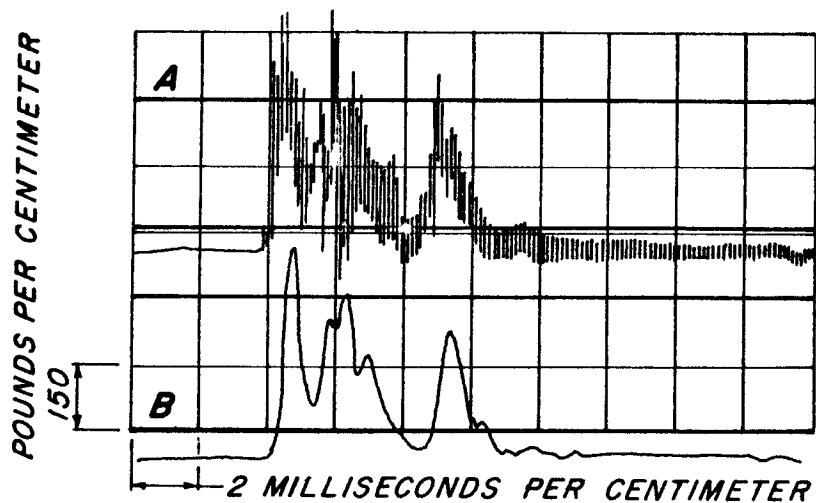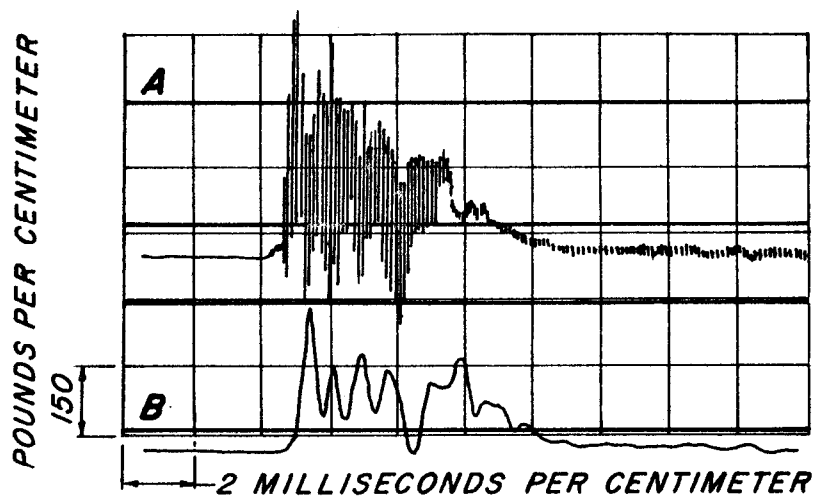3/4-inch lag screw in each cleat.

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Figure 2. - - Drawings of oscilloscope screen showing force-time pulses
for drop tests. Pulses in channel A show superimposed high-frequency
oscillations that have been filtered out in channel B. In the upper
drawing, pulses are shown from the third 9-inch drop test impact
against the side grain of a cleat secured with one 1/4-inch bolt. In the
lower drawing, pulses are shown from the initial 9-inch drop test im-
pact against the side grain of a cleat secured with two thirtypenny
nails.

Figure 3. --Pendulum-impact test setup, with pendulum platform in position to be released for 9-inch (vertical equivalent) impact. Hooked in the ring at the back end of the platform is the quick-release clevis attached to the pulling cable. The pulling cable passes through a pulley attached to an anchor post (not shown) and then to an overhead electric hoist (not shown). The dual-beam oscilloscope with Land camera and attachment are at left foreground.
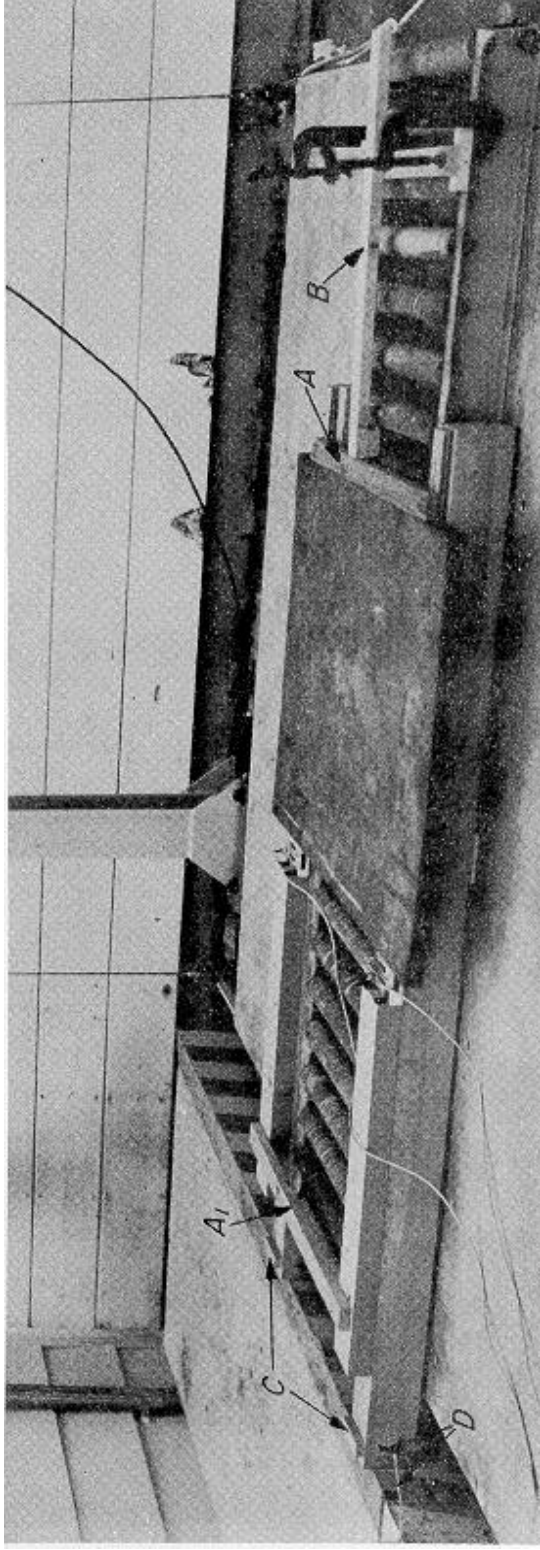
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**Figure 4.--Test setup used for thirtypenny nails, 3/4-inch bolts, and 3/4-inch lag screws. In all other pendulum-impact tests, the impact head plate rested directly on the two 4- by 4-inch main members. Here, the plate rests on rollers to eliminate possible effects of friction between plate and main members during impact. Lightly nailed cleats ($A_1$, $\underline{A}$) and brace ($\underline{B}$) were necessary to hold components in contact and alinement during the swing. Slip measurement reference blocks ($\underline{C}$) are shown at the left near the sweep synchronization trigger ($\underline{D}$).**
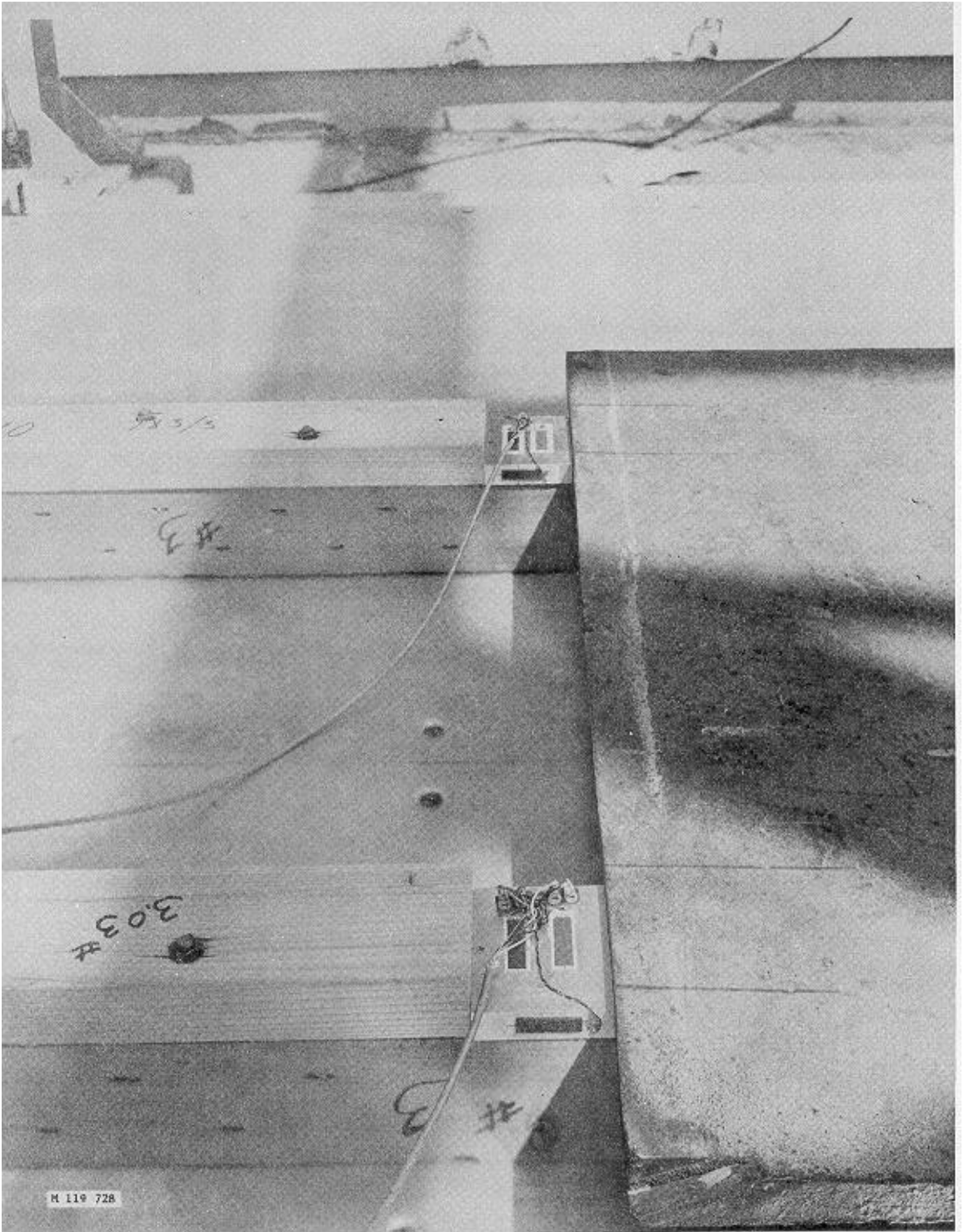
Figure 5. --Closeup view of the two load cells in place between the impact
head plate and the ends of the two test cleats.   Separate shielded cables
connect the load cells through the calibration boxes to the oscilloscope.
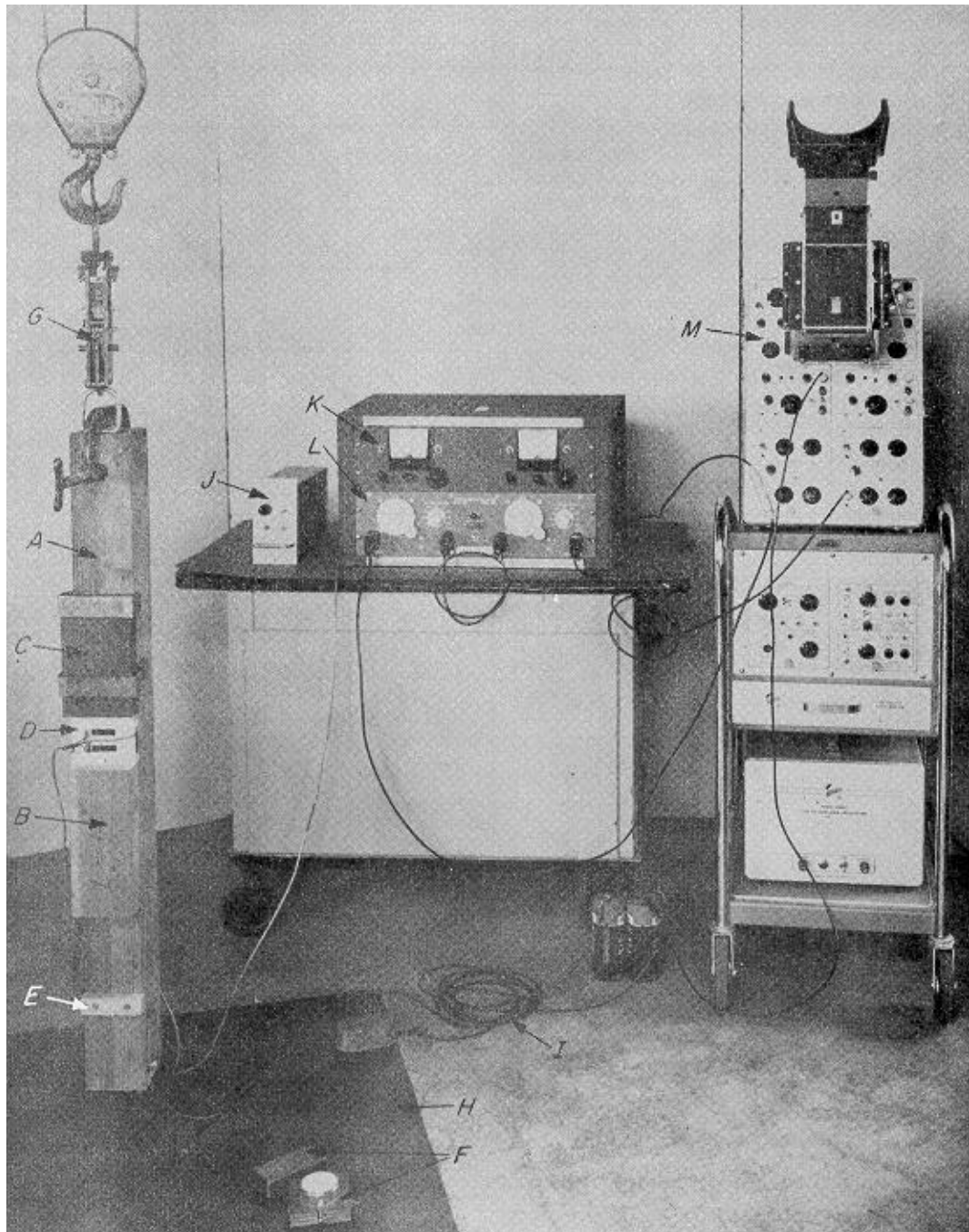
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Figure 6.-- Test setup and equipment used in drop tests of two-member joints.  A, main member; B, cleat; C, impact head; D, load cell; E, slip measurement reference block; F, dial gage and precision gage block; G, solenoid-operated release mechanism; H, steel plate impact surface; I, sweep trigger circuit; J, D-C preamplifier; K, calibration and junction box; L, filter; M, oscilloscope with viewing and camera attachment.
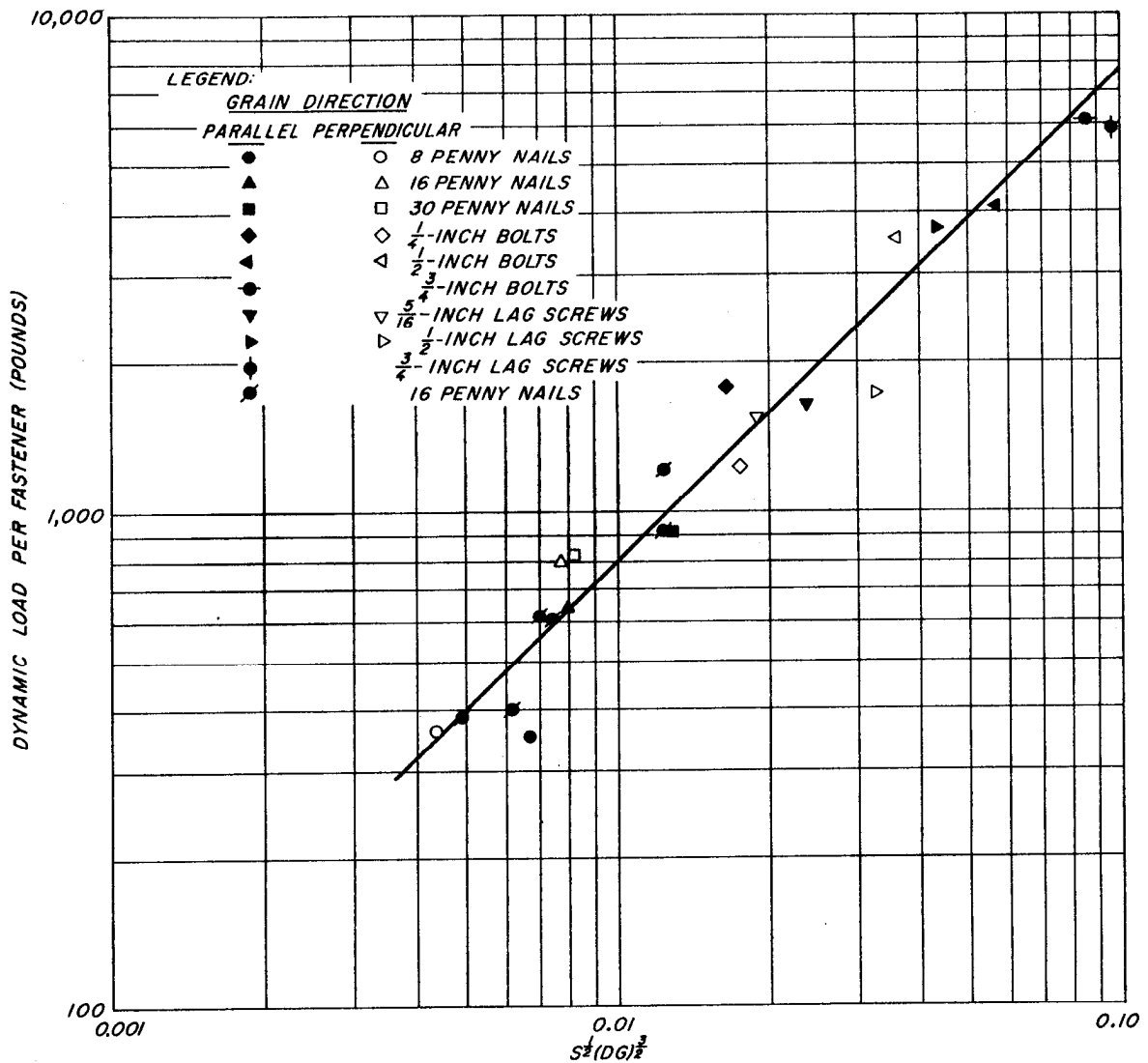
Figure 7. --Relationship between initial impact dynamic load, on a per fastener basis, and the term $S^{1/2}(DG)^{3/2}$ for all tests. $\underline{S}$ represents slip; $\underline{D}$, fastener diameter; and $\underline{G}$, average specific gravity of wood members. Each data point represents the average for 1 to 4 test joints.
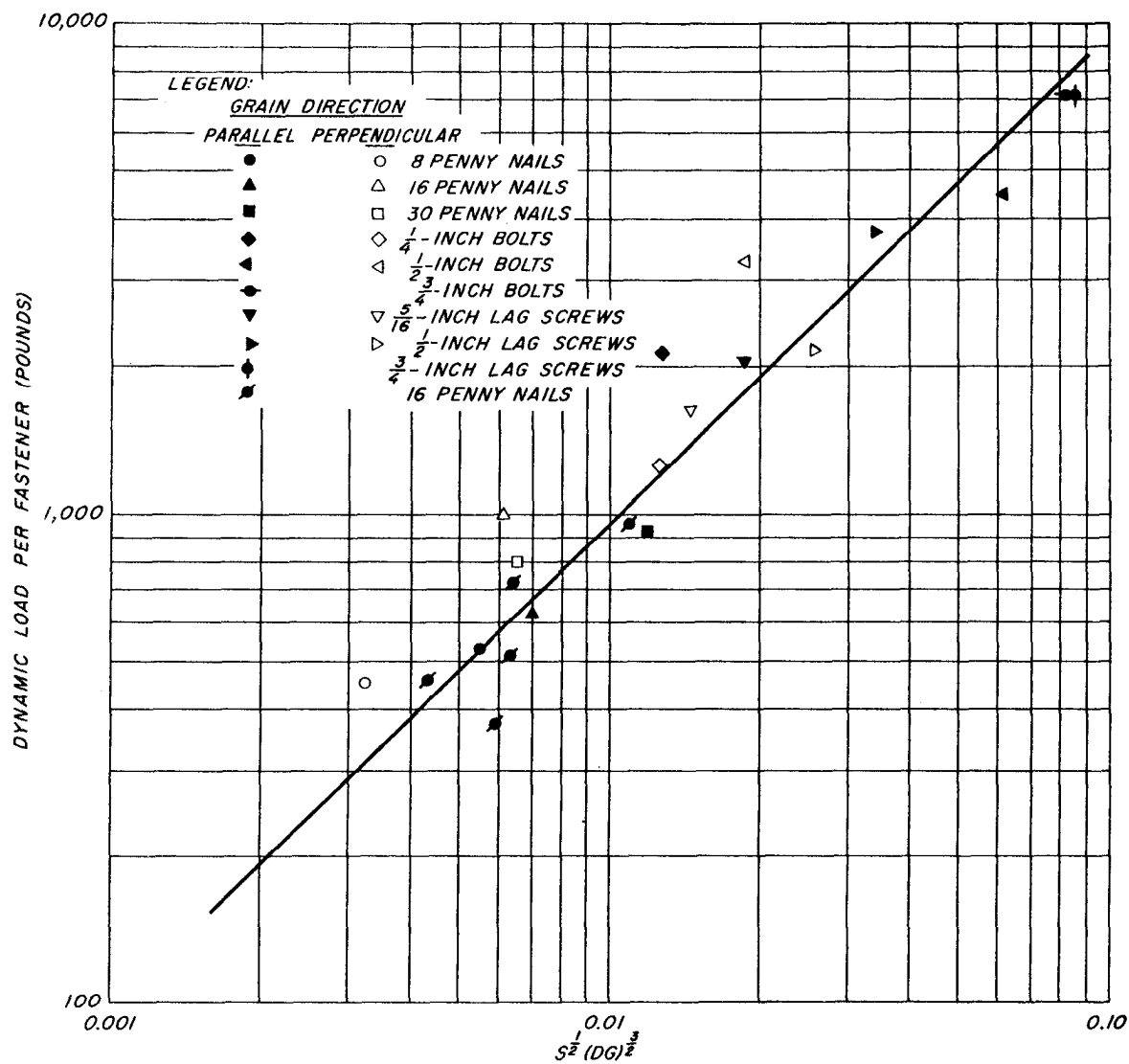
Figure 8. --Relationship between second impact dynamic load, on a per fastener basis, and the term $S^{1/2}(DG)^{3/2}$ for all tests. Each data point represents the average for 1 to 4 test joints.
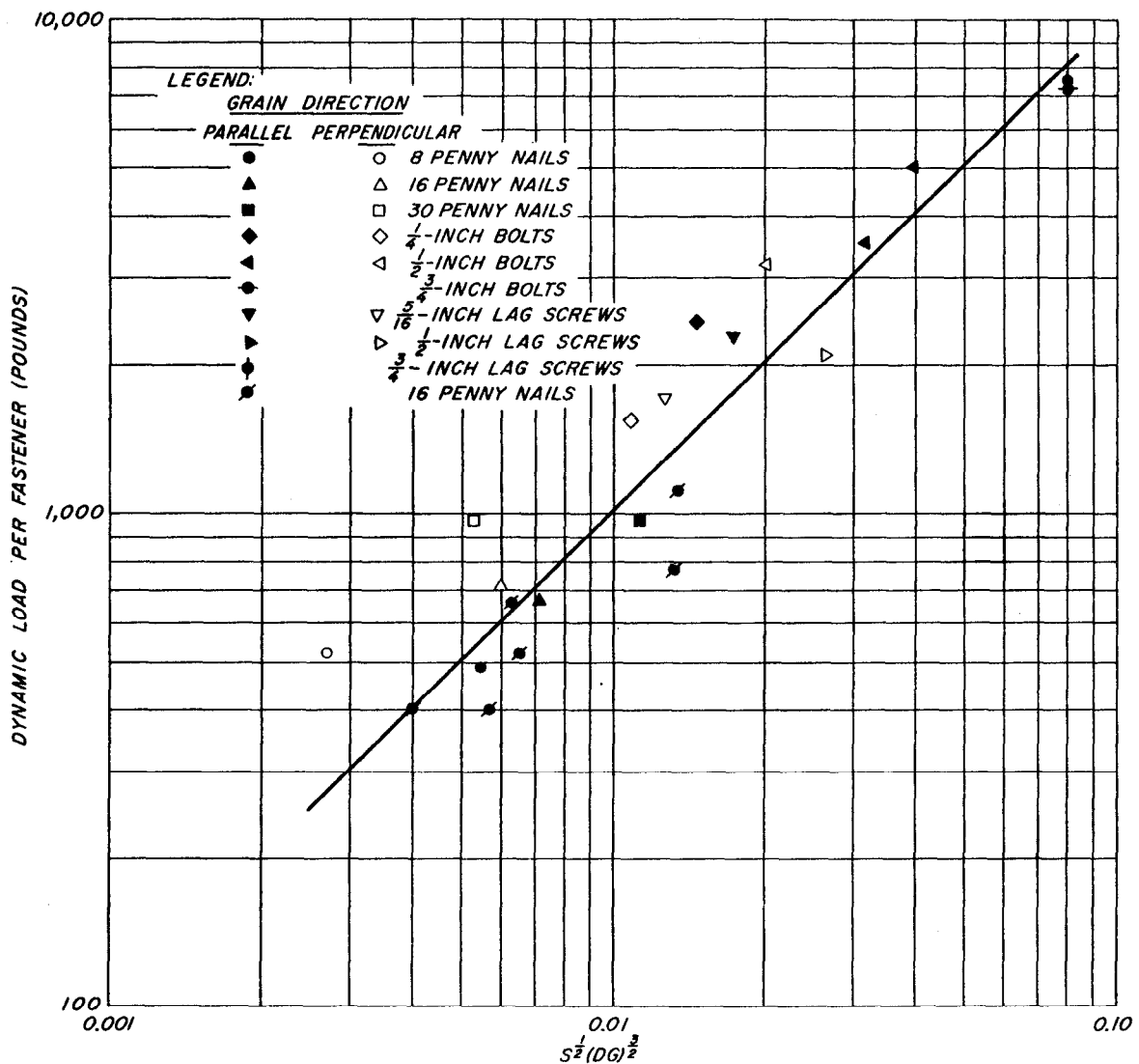
Figure 9.--Relationship between third impact dynamic load, on a per fastener basis, and the term $S^{1/2}(DG)^{3/2}$ for all tests. Each data point represents the average for 1 to 4 test joints.

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Figure 10.--Relationship between first, second, and third impact dynamic loads, on a per fastener basis, and the term $S^{1/2}(DG)^{3/2}$ for all tests. Each data point represents the average for 1 to 4 test joints.
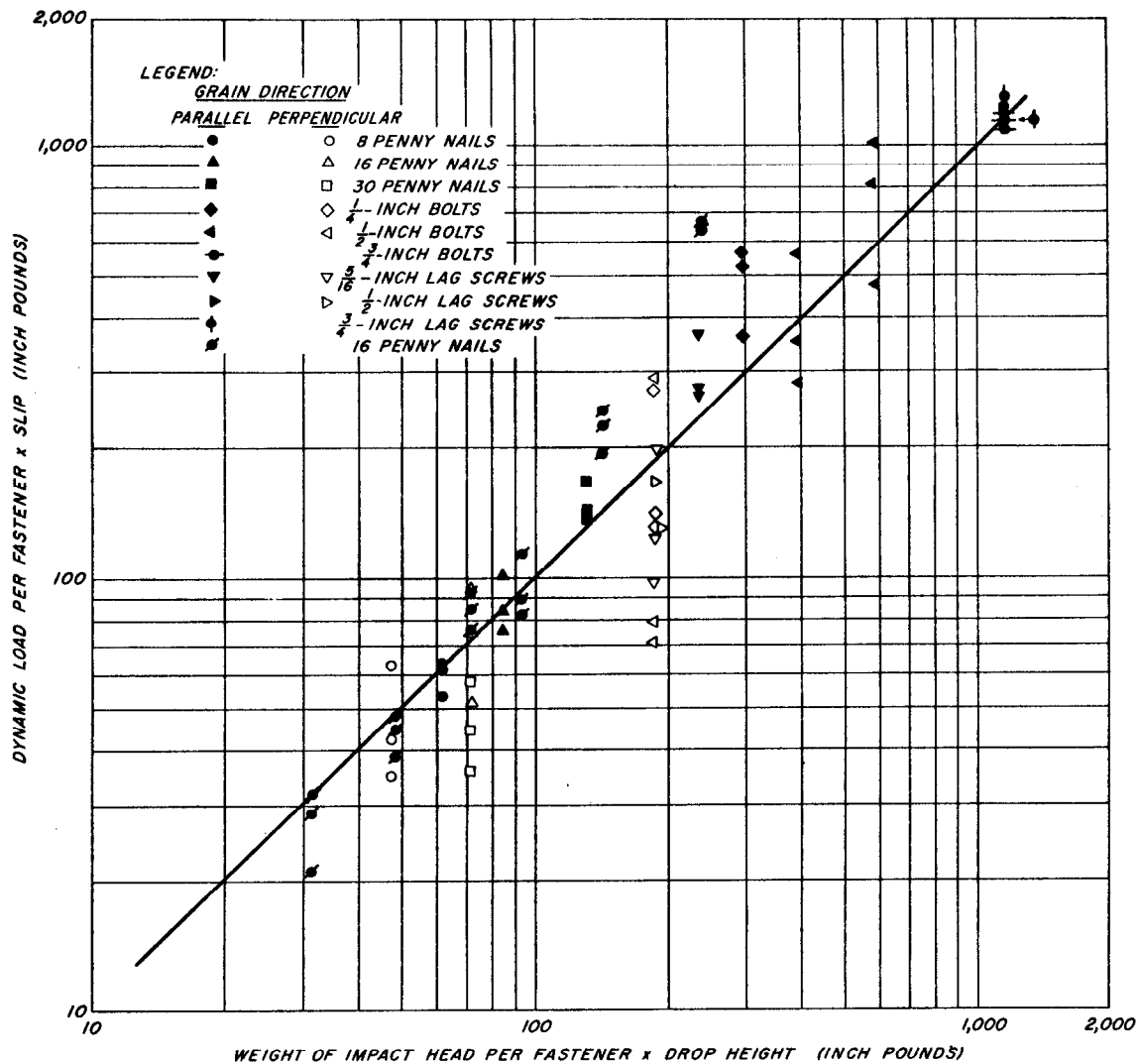
Figure 11.--Relationship between F S (dynamic load per fastener times slip) and W h (weight of impact head per fastener times drop height) for all tests. Each data point represents the average for 1 to 4 test joints.

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